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The *Guardian*

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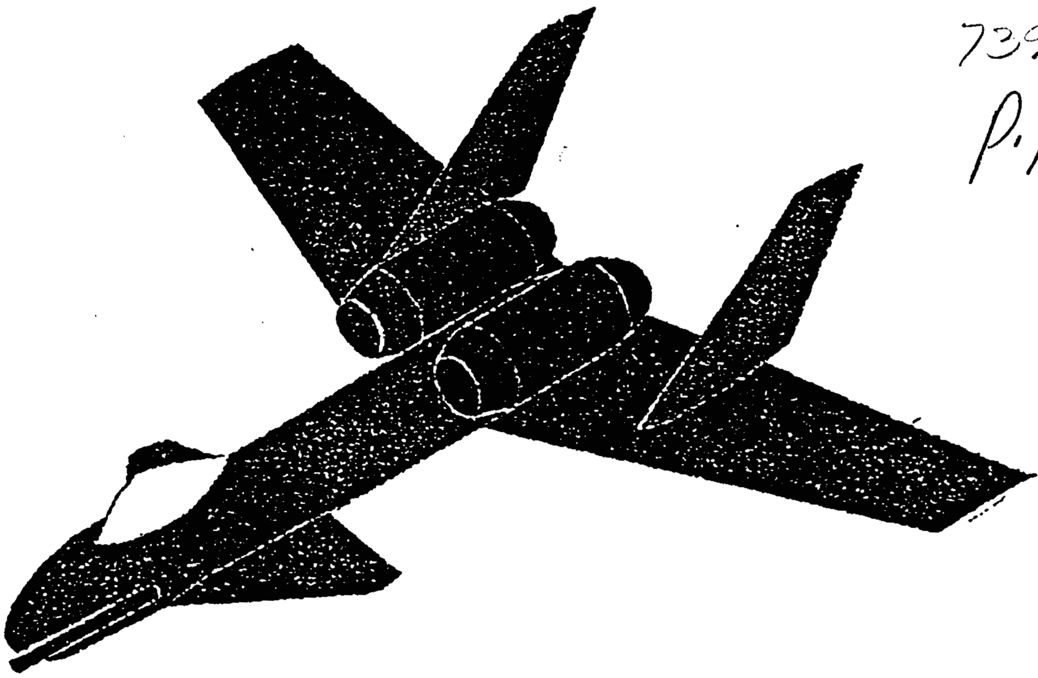

Preliminary Design of a Close Air Support Aircraft

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ABSTRACT

This report presents one design of a Close Air Support (CAS) aircraft. It is a canard-wing, twin engine, twin vertical tail aircraft that has the capability to cruise at 520 knots. The *Guardian* contains state-of-the-art flight control systems. Every effort has been made to make the *Guardian* survivable in a hostile environment.

Specific highlights of the *Guardian* include: 1) Low cost; the acquisition cost per airplane is $13.6 million for a production of 500 airplanes. 2) Low maintenance; it has been designed to be easily maintainable in unprepared fields. For example, the external engines allow easy access for repairs. 3) High versatility; the *Guardian* can perform a wide range of missions. Along with being a close air support aircraft, it is capable of long ferry missions, battlefield interdiction, maritime attack, and combat rescue

The *Guardian* is capable of a maximum ferry of 3800 nm, can take-off in a distance of 1700 feet, land in a ground roll distance of 1644 feet. It has a maximum take-off weight of 48,753 lbs, and is capable of carrying up to 19,500 lbs of ordinance.

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AR	aspect ratio
a	speed of sound
a.c.	aerodynamic center
b	wing span
CD	airplane drag coefficient
CDo	profile drag coefficient
Cj	thrust specific fuel consumption
CL	airplane lift coefficient
CM	airplane pitching moment coefficient
c	mean chord
cd	airfoil drag coefficient
cl	airfoil lift coefficient
cm	airfoil pitching moment
c,t	tip chord
c,r	root chord
e	Oswald efficiency factor
F.S.	fuselage station
f	equivalent parasite area
g	acceleraton due to gravity
I	mass moment of Inertia
L	lift
L/D	lift-to-drag ratio
l	length
M	free stream Mach number
Mdd	drag divergence Mach number
n	total airplane load factor
Ps	specific excess energy
P	power
p	perturbed roll rate
q	perturbed roll rate
q	shear flow
q	free stream dynamic pressure
r	perturbed roll rate
S	wing planform area
Sc	canard planform area
Sv	vertical tail area
T	airplane thrust
T/W	thrust-to-weight ratio

t/c	thickness ratio at the chord
U	steady air speed
V	shear force
W	airplane weight
W.L.	waterline
W/S	wing loading

Greek Symbols

a	angle of attack
ß	perturbed sideslip and sideslip
ρ	density
θ	fuselage cone angle
ν	kinematic viscosity

Supscripts

avail	available
cr	critical
f	fuselage
fc	fuselage cone
req	required
to	take-off conditions
xx	about body x-axis
wet	wetted
yy	about body y-axis
zz	about body z-axis
o	condition at 0 angle of attack

Derivatives

CLu	Lift-due-to-speed
CDu	Drag-due-to-speed
CMu	Pitching-moment-due-to-speed
CLa	Airplane Lift Curve slope
CDa	drag-due-to-angle-of-attack
CMa	Pitching-moment-due-to-angle-of-attack
CLadot	Lift-due-to-rate-of-angle-of-attack
CDadot	Drag-due-to-rate-of-angle-of-attack
CMadot	Pitching-moment-due-to-rate-of-angle-of-attack
CLq	Lift-due-to-pitch-rate

CDq	Drag-due-to-pitch-rate
CMq	Pitching-moment-due-to-pitch-rate
CLb	Lift-due-to-angle-of-sideslip
CDb	drag-due-to-angle-of-sideslip
CMb	Pitching-moment-due-to-angle-of-sideslip
CLbdot	Lift-due-to-rate-of-angle-of-sideslip
CDbdot	Drag-due-to-rate-of-angle-of-sideslip
CMbdot	Pitching-Moment-due-to-rate-of-angle-of-sideslip
Clr	Rolling-moment-due-to-yaw-rate
Cnr	Yawing-moment-due-to-yaw-rate
Cyr	Side-force-due-to-yaw-rate
Clp	Rolling-moment-due-to-roll-rate
Cnp	Yawing-moment-due-to-roll-rate
Cyp	Side-force-due-to-roll-rate
CLic	Lift-due-to-canard-incidence
CDic	Drag-due-to-canard-incidence
CMic	Pitching-moment-due-to-canard-incidence
Clds	Rolling-moment-due-to-spoiler differential
Cns	Yawing-moment-due-to-spoiler-differential
Cydr	Side-force-due-to-rudder-deflection
Cldr	Rolling-moment-due-to-rudder-deflection
Cndr	Yawing-moment-due-to-rudder-deflection

Acronyms

AIM	air intercept missile
AGM	air-to-ground missile
APU	auxilliary power unit
ARM	anti-radiation missile
ATF	advanced tactical fighter
CAS	close air support
ECM	electronic countermeasures
ECU	environmental control unit
FLIR	forward looking infrared
HOTAS	hands on throttle and stick
HUD	head up display
IFF	identification friend or foe
INS	inertial navigation system
LANTIRN	low altitude navigation and targeting infrared at night
LRF/D	laser range finder/designator
LRU	line replaceable unit

MAC	mean aerodynamic chord
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
RAT	ram air turbine
RDTE	research, development, testing, and evaluation
RFP	request for proposal
RWR	radar warning receiver
SHP	shaft horsepower
TACAN	tactical air navigation
TSFC	thrust specific fuel consumption
UHF	ultra high frequency
VHF	very high frequency

1.0

INTRODUCTION

The primary role of a CAS aircraft is support of ground troops. A typical scenario involves an infantry group under sudden artillery attack which may have insufficient ground support, leaving the troops with two options; retreat or imminent destruction. The commanding officer radios in for air support. This is where the CAS aircraft comes in.

The CAS aircraft must be able to take off quickly, without extensive preparation, often from unprepared runways. It must be able to get to the battle zone quickly, for time is of the essence. Navigation must be precise because pilots are usually operating in unfamiliar territory. The aircraft should have systems which allow it to differentiate friendly forces from unfriendly, as many times the enemy will already be engaged when the aircraft arrives. The aircraft must be able to carry extensive ordinance. It will inevitably be outnumbered, but it should have the advantage of surprise and maneuverability over enemy ground forces. In order to be effective it must destroy numerous enemy forces in just one sortie.

2.0

Mission Description

The *Guardian* was designed for a low level mission as described from the specifications outlined by the RFP. The *Guardian* was also expected to meet two additional missions: A high-low-low-high mission and a ferry mission. Profiles of all three of these missions are shown in Figures 2.1, 2.2, and 2.3.

2.1 Low Level Mission

1 Warm up and taxi
2 Take off and accelerate to cruise speed
3 Dash at sea level at the lower of 500 knots or the maximum speed at military power to a point 250 nautical miles from takeoff
4 Combat: Two combat passes at sea level with speed equal to maximum speed equal to maximum speed in military power minus 50 knots. Each combat pass consists of a 360 degree sustained turn plus a 4000 feet energy increase. Drop air to ground weapons, but retain pylons, racks, and ammunition
5. Dash at sea level at the lower of 500 knots or maximum speed atmilitary power 250 nautical miles to return to base
6. Land with fuel for 20 min endurance at sea level

Mission Specifications

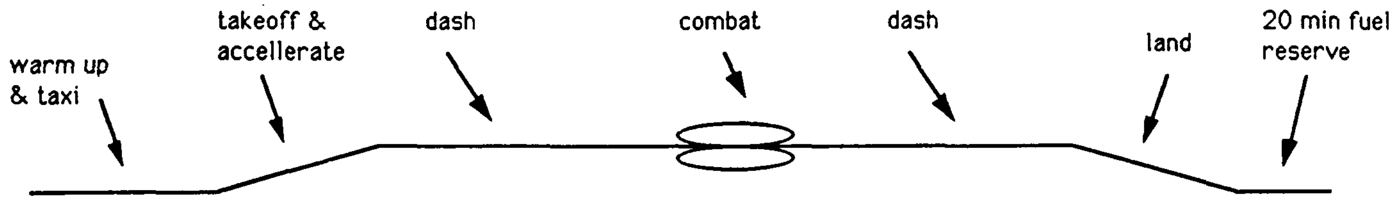


Figure 2.1 Low Level Mission

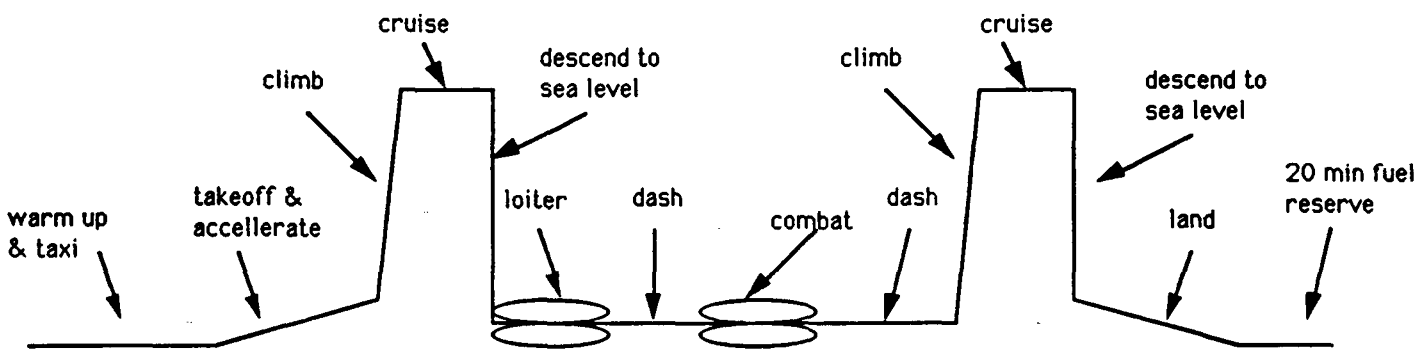


Figure 2.2 High-Low-Low-High Mission

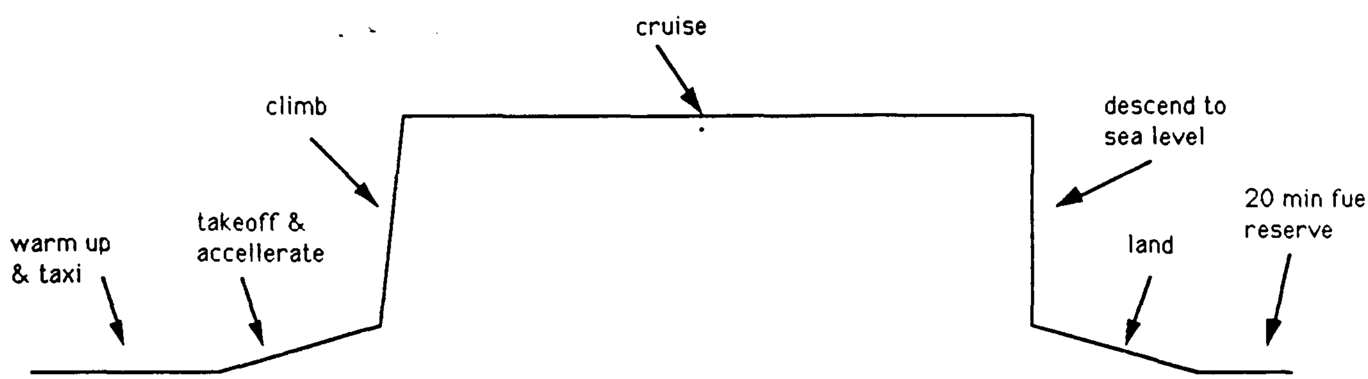


Figure 2.3 Ferry Mission

2.2 High-Low-Low-High Mission

1 Warm up and taxi
2 Take off and accelerate to cruise speed
3 Climb on course at intermediate power to best cruise altitude and speed
4 Cruise outbound at best altitude and speed to a total accumulated range of 150 nautical miles
5 Descend to sea level
6 Loiter at sea level at best speed for maximum endurance for a time as determined by the fuel and payload
7 Dash 100 nautical miles at sea level
8 Combat: Two combat passes at sea level with speed equal to maximum speed equal to maximum speed in military power minus 50 knots. Each combat pass consists of a 360 degree sustained turn plus a 4000 feet energy increase. Drop air to ground weapons, but retain pylons, racks, and ammunition
9 Dash 100 nautical miles at sea level
10 Climb (on return course) to best cruise altitude and speed
11 Cruise back at best altitude and speed to a total distance of 150 nautical miles
12 Descend to sea level
13 Land with fuel for 20 minutes endurance at sea level

2.3 Ferry Mission

1 Warm up and taxi

2 Take off and accelerate to cruise speed

3 Climb on course at intermediate power to best cruise altitude and speed

4 Cruise outbound at best altitude and speed to a total accumulated range of at least 1,500 nautical miles

5 Descend to sea level

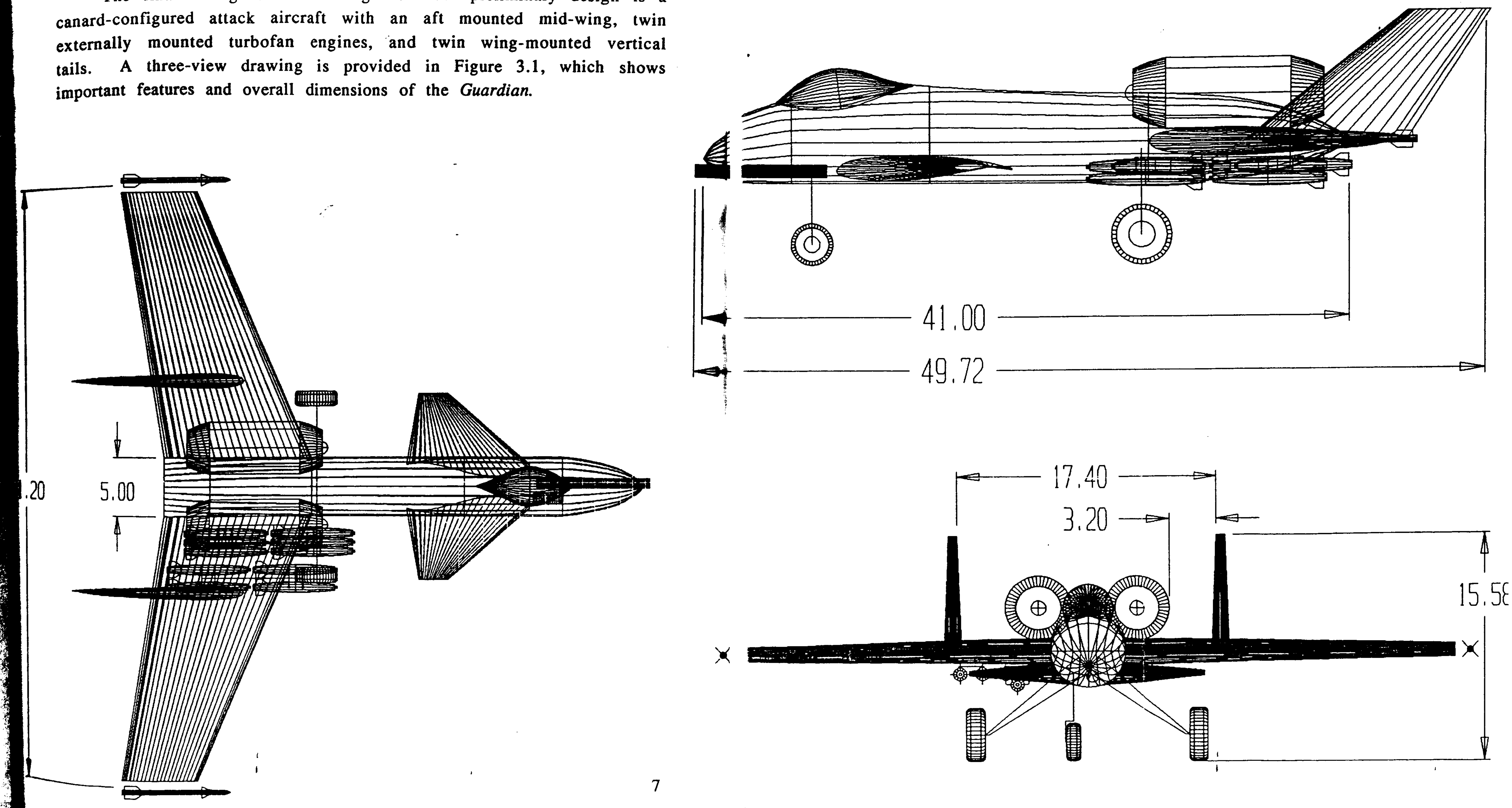
6 Land with fuel for 20 minutes endurance at sea level

1.
FOLDOUT FRAME

3.0 FINAL CONFIGURATION

The final configuration resulting from our preliminary design is a canard-configured attack aircraft with an aft mounted mid-wing, twin externally mounted turbofan engines, and twin wing-mounted vertical tails. A three-view drawing is provided in Figure 3.1, which shows important features and overall dimensions of the *Guardian.*

2.
FOLDOUT FRAME



4.0 PRELIMINARY SIZING ANALYSIS

4.1 Preliminary Weight Sizing

For initial estimates in preliminary design, empirical data were used based on the specifications established in the RFP. Initial sizing of the configuration was based on the low level mission. The results of this preliminary design are shown in Table 4.1

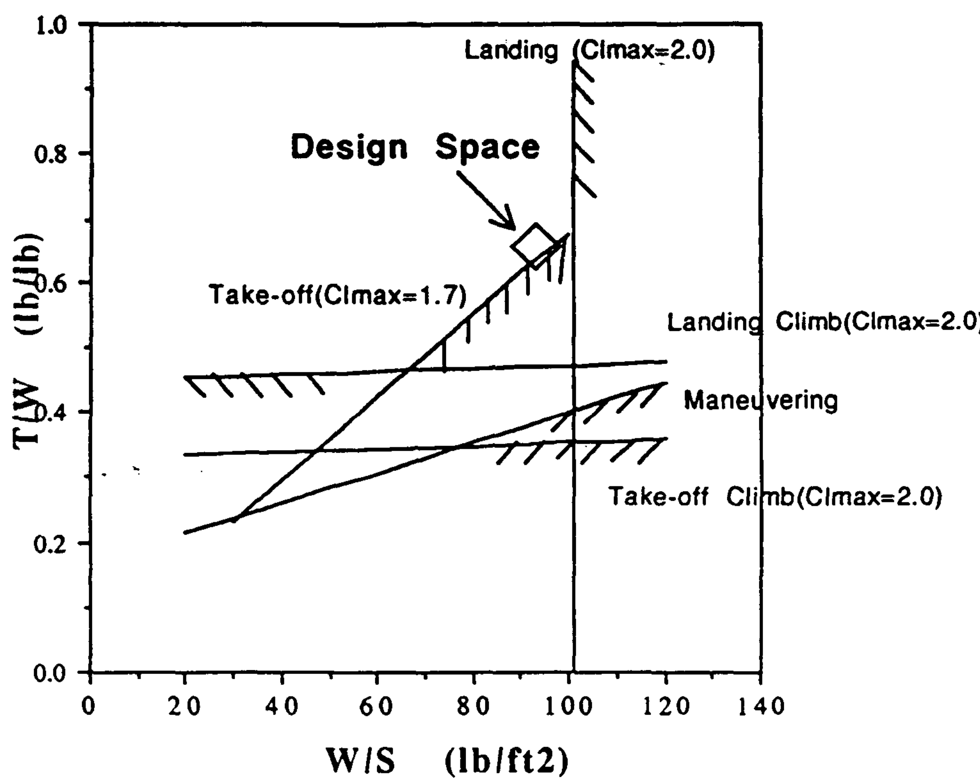
Table 4.1
Preliminary Design Results

Take-off Weight (lbs)	50050
Payload Weight (lbs)	15658
Mission Fuel Weight (lbs)	10588
Operating Empty Weight (lbs)	26094
Trapped Fuel/Oil Weight (lbs)	250
Crew Weight (lbs)	225
Empty Weight (lbs)	25619

4.2 Performance Sizing

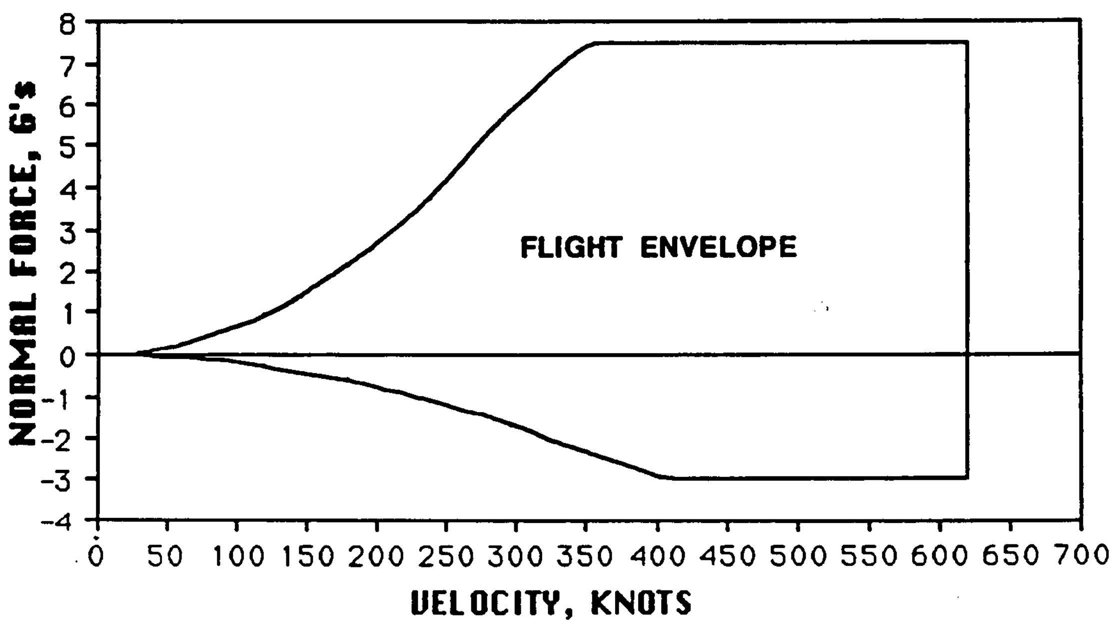
After estimating a preliminary weight, the next step was to determine the optimum Thrust-to-Weight ratio (T/W) and wing loading (W/S) for the *Guardian*. This point or area would be a starting point for the initial design's of the *Guardian*. Figure 4.1 shows the Matching Gragh for the *Guardian*. From this graph, the *Guardian*'s design point was chosen to be near T/W = .62 and a W/S of 100. From an initial weight of 55,000 pounds, the guardians initial thrust was 34,100 lbf and the wing area was 550 ft^2. These figures were not by any means the "ideal" figures, but provided a good initial starting point.

Figure 4.1 Matching Graph for the Guardian



To find the maximum load that the airplane is capable of, a V-n diagram is employed. Figure 4.2 shows the V-n diagram for the *Guardian*. The upper and lower limits of the *Guardian,* seven and minus three respectively, are determined from its structural capability. At lower speeds, the maximum g's that the Guardian is capable of pulling is determined by airspeed, air density, and the aircrafts lift coefficient.

Figure 4.2 V-n Diagram for the Guardian



5.0

CONFIGURATION

5.1 The *Guardian*

A three-view drawing of the *Guardian* is shown in Figure 5.1. The following section discusses the major features of the *Guardian*, and also other options considered. This section also discusses the reasons and justifications for our choices.

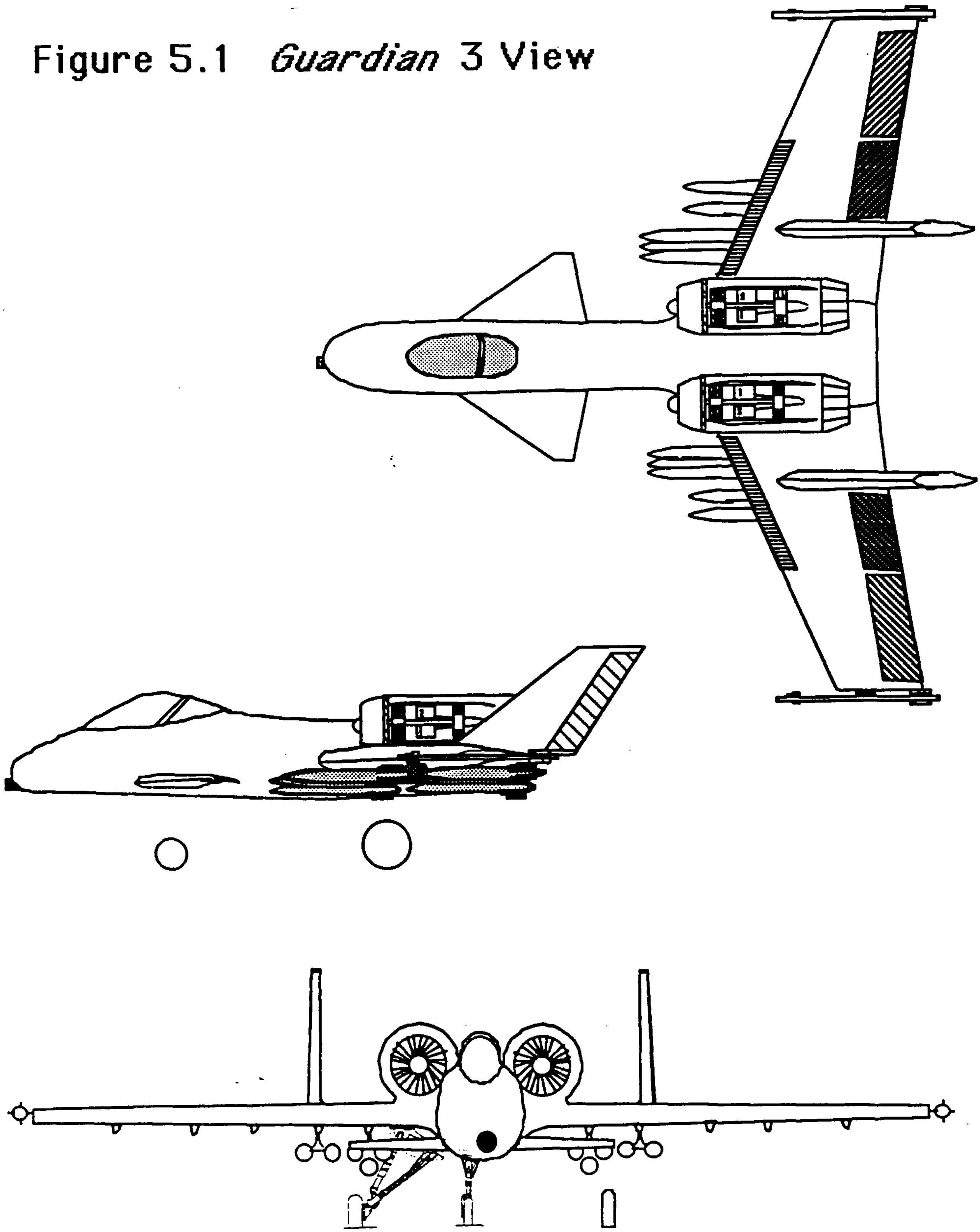
5.1.1 Canard-Wing Configuration

The general configuration chosen for the *Guardian* to meet the CAS requirements was a canard-wing configuration. The canard is of value because it can stall before the wing stalls, thus producing a nose down pitching moment. Also, two lifting surfaces (the canard and the wing) is more efficient than one lifting surface (the wing) and one negative lifting surface (the horizontal stabilizer). Although canards are usually considered detrimental to pilot vision, the canard is a much smaller hindrance than would be a forward wing. This is especially important in the close air support role.

5.1.2 Twin, High Mounted engines

The twin engines were placed in the rear of the aircraft, mounted above the fuselage. The high placement keeps the engines well protected from gunfire and missiles. Both the wings and the vertical tails act as a

Figure 5.1 *Guardian* 3 View



screen for the engines. The external mounts also allow for easy accessibility and maintainability. One requirement of this aircraft is that is must be maintainable on the field without the benefit of the most convenient equipment. This can be accomplished with the *Guardian* since the engines are easily accessible.

5.1.3 Twin Vertical Tails

In a hostile environment, one large vertical tail can be an easy target for enemy fire. The twin vertical tails on the *Guardian* are therefore desirable since two smaller tails are less of a target than one large one. Another benefit associated with a twin tail configuration.is redundancy. In the case that one tail does get hit there will still be one functioning surface for directional control. The vertical tails protect the engines from ground fire and also mask the heat signature from the engine exhaust, thus making it more difficult for a heat seeking missile to hit the *Guardian*.

5.2 Other Configuration Options

5.2.1 Conventional Configuration

A conventional wing-elevator configuration has been used in the past for the CAS role. A conventional configuration is the easiest, and

cheapest design for stability purposes. During an attack, the pilot has enough things to worry about without dealing with aircraft control. The conventional design, though, cannot offer the maneuverability that a canard-wing configuration can. Also, in a conventional design, the wing, especially a low wing, could be a hindrance to the pilot's view.

5.2.2 Joined Wing Configuration

A joined wing configuration is a fairly close design to the canard-wing configuration. There is still two lifting surfaces, and the two connected wing tips reduce vortices at the tip, resulting in less induced drag. The joined wings require less structural material for a given load, but they are much more difficult and expensive to manufacture. Cost is the major downfall of the joined wing. Both construction and especially research costs will greatly rise. Also, the joined wing configuration is an undeveloped and unproven technology.

5.2.3 Internally Mounted Engines

Engines mounted inside the fuselage means less profile drag for the aircraft, resulting in better aerodynamic characteristics and better fuel efficiency. This also makes the aircraft look more slick. Although fuel efficiency is always a factor, it does not need to be considered a critical design criteria, especially when there will already be 20 bombs under the wing. So allowing for the higher drag, one can gain several advantages by

mounting the engines externally. The fuselage will have more room for other components, such as fuel and landing gear, and still be smaller and shorter than a fuselage with internal engines.

6.0

FUSELAGE LAYOUT

6.1 Fineness Ratio

The diameter of the *Guardian* fuselage is five feet and the length is forty-one feet. The tail-cone fineness ratio is defined as the ratio of the tail-cone length to the fuselage width. With its tail-cone designed to about thirteen feet in length, the *Guardian* has a tail-cone fineness ratio of 2.6. The fuselage fineness ratio is defined as the ratio of the fuselage length to the fuselage width. See Figure 6.1. The *Guardian* has a fuselage fineness ratio of 8. Both the *Guardian's* fuselage cone angle of six degrees and its fuselage fineness ratio of 8 are within currently used fuselage parameters for fighter aircraft (Ref 1). However, the tail-cone fineness ratio of 2.6 is slightly below currently used parameters. This is acceptable, though, because the tail-cone fineness ratio is somewhat interpretive and the 2.6 value is not significantly off from the desirable 3 to 5 range (Ref 1).

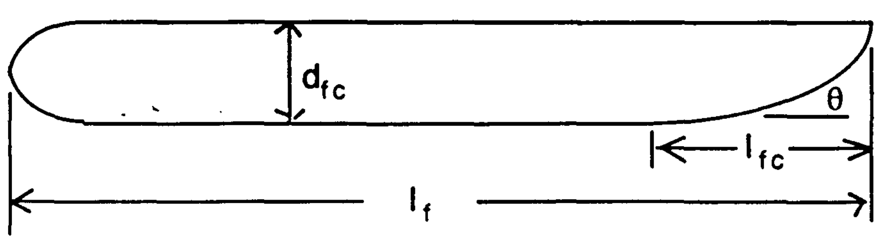


Figure 6.1 Definition of Geometric Fuselage Parameters

6.2 Internal Layout

The layouts of all systems in the *Guardian* were designed around easy access, efficient use of space and survivability and are illustrated in Figure 6.2. Fuel tanks were confined to the fuselage to increase survivability, reduce weight in the wing and accommodate the heaviest ordnance configurations on the wings. Such heavy ordnance configurations are required by certain mission profiles and the *Guardian* is ready to deliver the greatest possible firepower without sacrificing performance. This confinement of the fuel tanks fills much of the fuselage and simplifies control of the center of gravity travel.

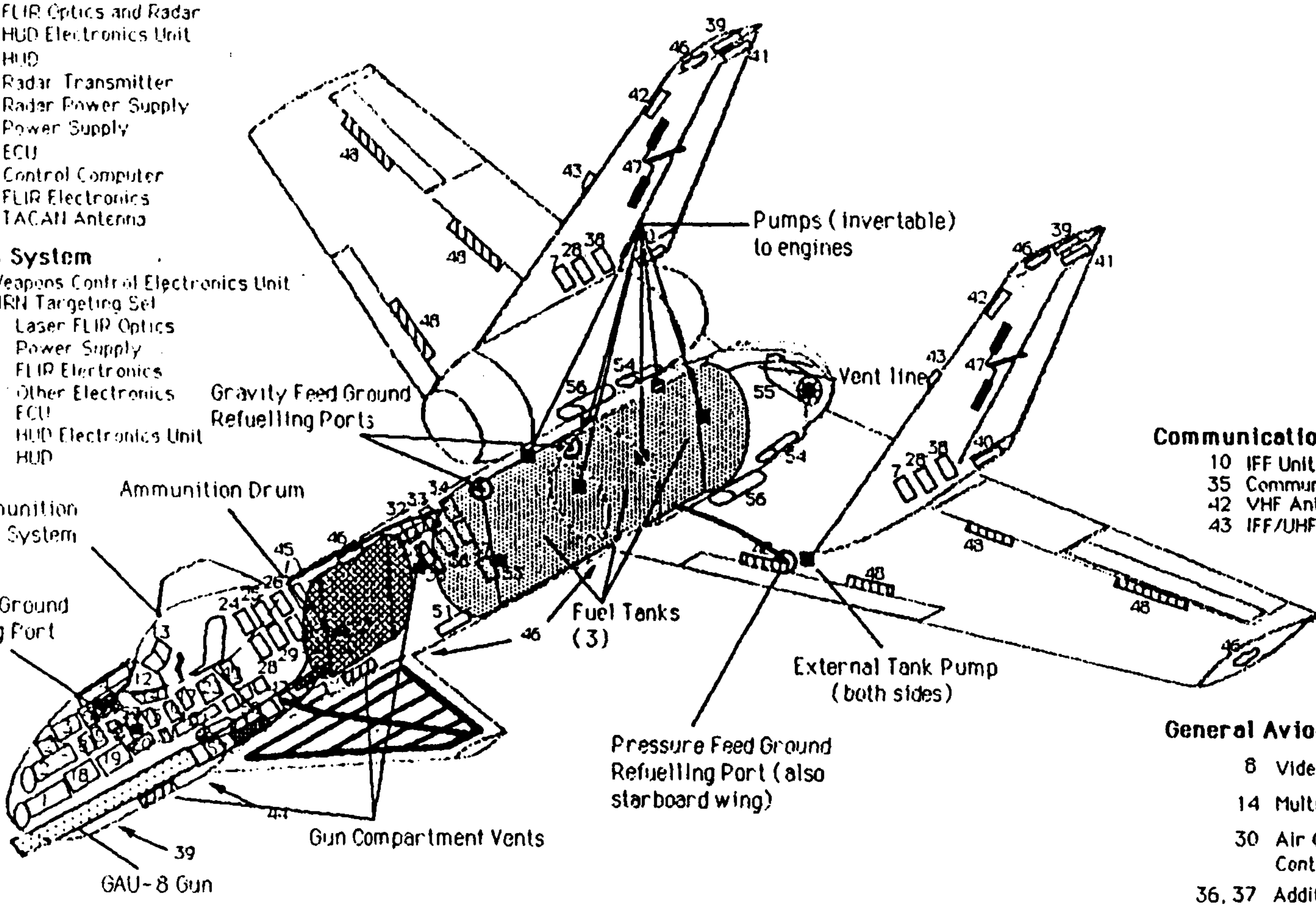
With the GAU-8 Cannon System (including ammunition drum) and all three landing gear also stored inside the fuselage, locations for avionics are mainly in the nose and around the cockpit. Some space between the GAU-8 ammunition drum and the forward fuel tank fire-wall was taken advantage of for locating a back-up flight control computer and a pair of expansion/mission-specific avionics locations. Because the *Guardian* does not incorporate a conventional radar system, most of the components of both the LANTIRN navigation and targeting systems pods fit into the *Guardian's* nose. The remaining LANTIRN electronics fit around the cockpit area. Internalizing the LANTIRN system was deemed important because of its proven flexibility and superiority over other systems (Ref 4). Because many avionics units are in close proximity, environmental control units are used frequently throughout the *Guardian*. Even with the clusters of avionics, the was ample space available for the required systems and subsystems. These systems and subsystems are covered in detail in sections 15 and 16.

Navigation System

- 9 INS Unit
- LANTIRN Navigation Set
  - 1 FLIR Optics and Radar
  - 12 HUD Electronics Unit
  - 13 HUD
  - 18 Radar Transmitter
  - 19 Radar Power Supply
  - 20 Power Supply
  - 21 ECU
  - 22 Control Computer
  - 23 FLIR Electronics
  - 45 TACAN Antenna

Weapons System

- 11 Weapons Control Electronics Unit
- LANTIRN Targeting Set
  - 2 Laser FLIR Optics
  - 3 Power Supply
  - 4 FLIR Electronics
  - 5 Other Electronics
  - 6 ECU
  - 12 HUD Electronics Unit
  - 13 HUD



Electronic Countermeasures (ECM) and Radar Warning Receiver (RWR) Systems

- 7 DF Reciever
- 17 ECM Control Computer
- 24 Forward Repeater
- 25 C/D Reciever
- 26 Analysis Processor
- 27 Techniques Generator
- 28 Power Amplifier
- 29 ECU
- 32 S/H Reciever
- 33 S/H Controller
- 38 Aft Repeater
- 39 DF Antenna
- 40 Aft Jamming Antenna
- 41 Radar Warning Receiver
- 42 VHF Antenna
- 43 IFF/UHF Antenna
- 44 C/D Antenna

Communications System

- 10 IFF Unit
- 35 Communications System Control Unit
- 42 VHF Antenna
- 43 IFF/UHF Antenna

General Avionics Components

- 8 Video Recorder
- 14 Multi-purpose Display
- 30 Air Conditioning and Environmental Control Systems Control Computer
- 36, 37 Additional Electronics Slots

Electrical System

- 3 Power Supply
- 16 Electrical System Control Computer
- 19 Radar Power Supply
- 20 Power Supply
- 28 Power Amplifier
- 46 Light Beacon
- 50 Batteries
- 51 Accumulator

Auxiliary Power and Landing Gear Systems

- 52 PAT
- 53 Landing Gear Hydraulics
- 55 Auxiliary Power Unit
- 56 Engine Driven Generators

Flight Control System

- 15 Flight Control Computer
- 31 Back-up Flight Control Computer #1
- 34 Back-up Flight Control Computer #2
- 47 Linear Electrohydrostatic Actuators
- 48 Rotary Electrohydrostatic Actuators
- 49 HOTAS Interface Control Computer

Air Conditioning and Environmental Control Systems

- 6 Environmental Control Unit (ECU)
- 21 ECU
- 29 ECU
- 30 Air Conditioning and Environmental Control Systems Control Computer
- 54 Engine Driven Pump

Figure 6.2 Fuselage Layout

6.3 Cockpit Layout

The design of the *Guardian* cockpit is based on conventional layouts. Because the *Guardian's* primary mission is at low altitude, the seat declination angle, twenty-five degrees, is a little less than most fighter aircraft. This attitude keeps the pilot in an aggressive visual posture at all times with a 20° over-the-nose visibility. The *Guardian's* primary mission also requires excellent over-the-side visibility. This is achieved with an over-the-side visibility angle of 51°. High G-factors are not prevalent in the *Guardian's* combat role, avoiding the need for a more declinated seat. The canopy width is five inches greater than that of the thirty inch frame width. Ample head clearance is provided (six and one half inches) for safe operation of the McDonnell Douglas ACES 2 ejection seat. An all "glass" instrument layout to be based on the new layout philosophy of the ATF aircraft will be installed. The HOTAS system will also be incorporated.

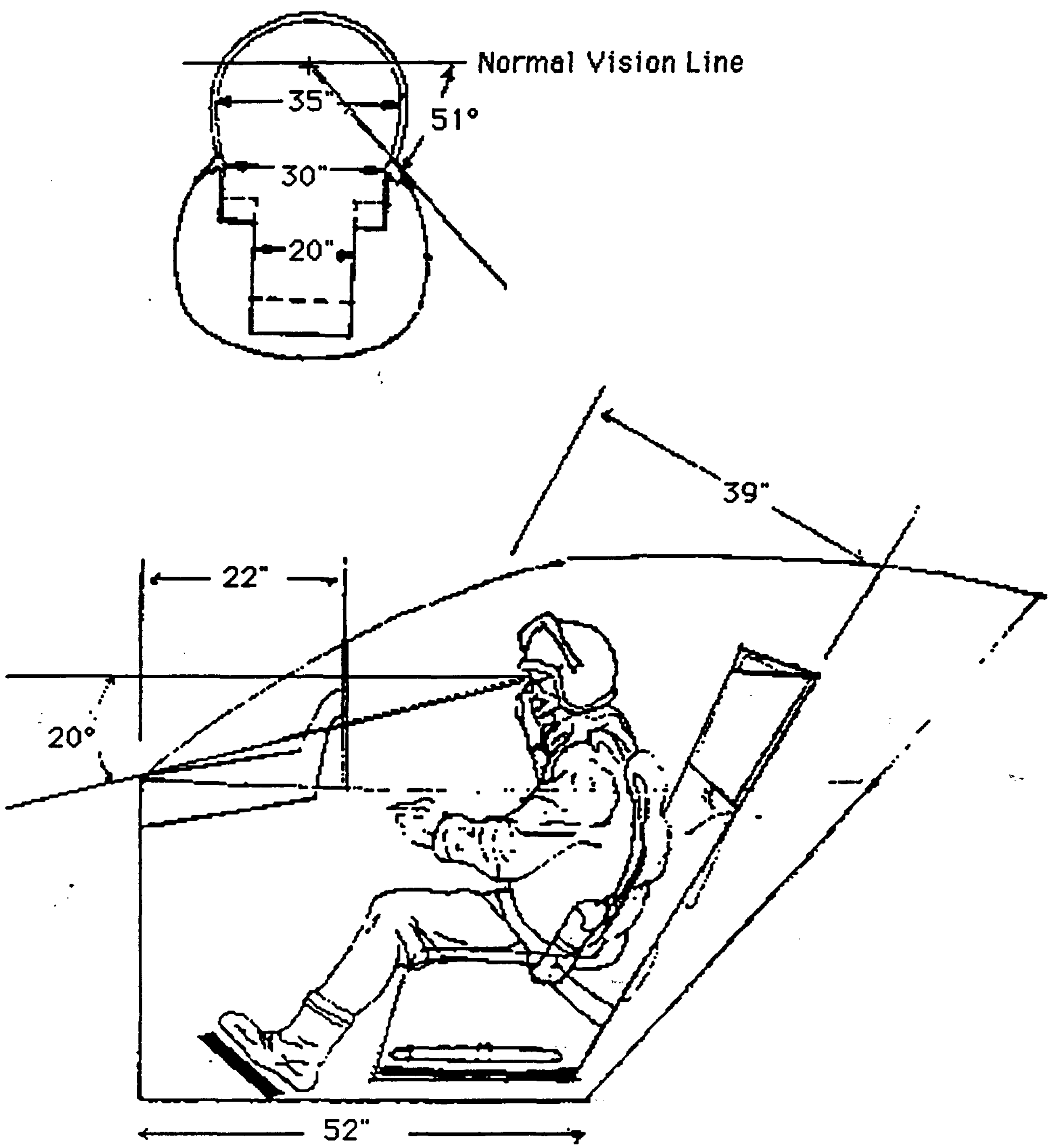


Figure 6.3   Cockpit Layout

7.0

WING PLANFORM

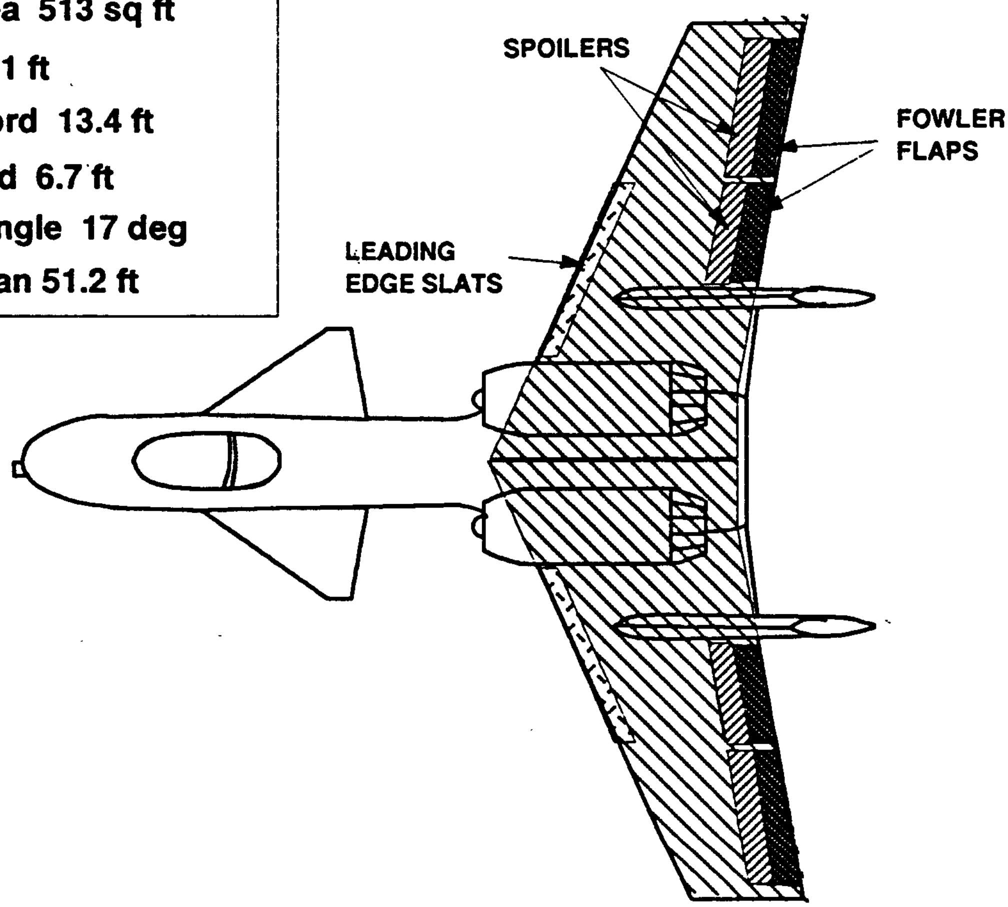
The wing planform layout for the *Guardian* is shown in Figure 7.1. The wing area of 513 ft^2 was determined to give a wing loading of 95 psf, which is high as possible while still being able to meet landing requirements The wing span is 51.2 feet, the mean chord is 10.1 feet, and the taper ratio of the wing is 0.5. The 17 degrees sweep and the DSMA 523 supercritical airfoil combine to delay Mach drag divergence effects from Mach 0.75 to 0.83. See Figure 13.3. This is especially important for this mission, which requires the aircraft to cruise at Mach 0.75. The DSMA 523 airfoil also has an even pressure distribution, which allows for better structural integrity.

With an airplane such as the *Guardian* that has a high wing loading, a good deal of high lift is required during take-off and landing. For this reason, single stage fowler flaps combined with leading edge slats were chosen. The fowler flaps do cost more than other simpler types of flaps, but the added lift is necessary. As can be seen in Figure 7.1, the fowler flaps extend from the wing tips to the vertical tails.

Because the fowler flaps extend over most of the wing span, spoilers were the most suitable choice of roll control devices for the *Guardian*. The spoilers can be placed in front of the flaps, as opposed to ailerons which could not fit onto the wing with the fowler flaps.

Figure 7.1 Wing Planform

Wing Area 513 sq ft
MAC 10.1 ft
Root Chord 13.4 ft
Tip Chord 6.7 ft
Sweep Angle 17 deg
Wing Span 51.2 ft

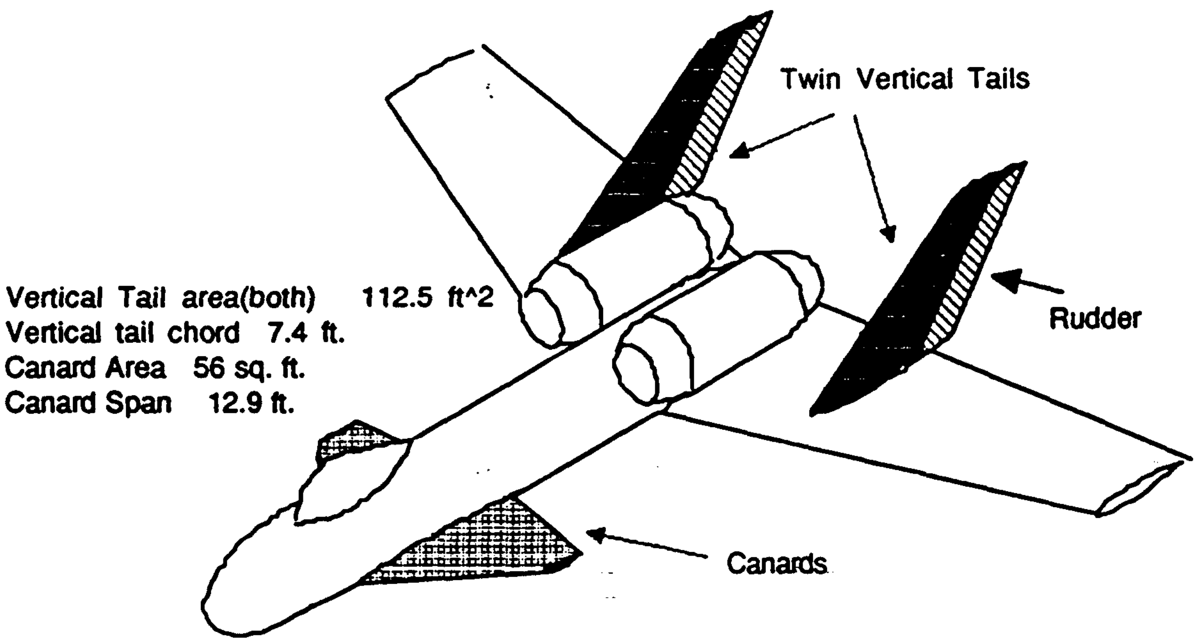


8.0

EMPENNAGE

The *Guardian*'s empennage consists of the canard and the vertical tails. Figure 8.1 shows the empennage with dimensions and its position relativeto the wing.

Figure 8.1 Empennage



8.1 Canard

A canard-wing configuration makes the *Guardian* more maneuverable, and therefore, more survivable than a conventional wing-elevator configuration. The canard is used for horizontal control, gun exhaust control, and wing stall prevention. Preventing wing stall is especially

critical in CAS where the aircraft is so close to the ground. There is no room to recover from a stall. Another major advantage of the canard over a conventional tail is that it is a lifting surface, as opposed to an elevator which is actually "lifting down". Low placement of the canard was chosen so that the canard downwash would not interfere with the flow into the engine inlets. The canard will be a fully actuated surface for longitudinal control, instead of employing any type of elevator or flap. The canard is fully actuated since all of its surface area will be needed for control. The canard, like the wing, uses the DSMA 23 airfoil for reasons similar to those described above. The canard area, 56 sq. ft, and its position were chosen from the longitudinal static stability analysis to give the *Guardian* a static margin of 5% at take-off.

8.2 Vertical Tails

The twin vertical tails are placed above the wing outboard of the engines. This placement provides protection for the engines from ground fire and also masks the heat signature from the engine exhaust. The advantages of twin tails instead of a single tail include redundancy, smaller cross section and easier construction. If one tail gets hit by ground fire, all lateral control will not be lost since there is still one tail left. Since two tails are employed instead of one, the smaller cross section means that the plane will be much less of a target from the side. Both of these properties makes the *Guardian* more survivable.

9.0. PROPULSION INTEGRATION AND AIRCRAFT PERFORMANCE

9.1 Engine Selection

9.1.1 Propulsion Type

As the operating range of this aircraft is in the high-subsonic velocity regime, and as range and power requirements are quite stringent, twin low bypass turbofan engines were chosen for the propulsion system. Because excellent fuel efficiency has been achieved at these velocity ranges for unducted fan engines, they were seriously considered, but were rejected do to their inherently high radar signature, increased likelihood of blade damage in hostile environments, and possible maintenance problems due to the newness of the technology. Other propulsions systems including turboprop and turbojet engines were also rejected due to poor performance in the velocity region of 500 knots. The low bypass turbofan engine supplied had very good performance characteristics compared to other turbofan engines, and was convenient to use, as sizing allowed excellent propulsion matching and eliminated unnecessary thrust and therefore weight.

9.1.2 Engine Sizing

Installed thrust of each sized engine is 15,113 lbs. at sea-level, while being 11.25 ft long and weighing 3640 lbs. each. This engine

selection achieved the limiting performance goals of: takeoff in under 2000 ft distance, sea-level dash at 500 knots, and fuel consumption allowing completion of all mission requirements. The following sections describe details of propulsion system integration and the performance achieved.

9.1.3 Engine Augmentation

Engine augmentation was considered primarily due to the fact that smaller and lighter engines could be used to provide the same T/W ratio. Preliminary estimates showed that engine weight could be reduced from 3640 lbs to only 2950 lbs each, with an inlet area reduction of from 44 inches to only 36 inches. However, later drag estimates showed that although the smaller engines could cruise efficiently at altitude without afterburners, the dash speed requirements (sea level) were only attainable with afterburners on. The fact that TSFC was too low with these conditions, as well as the fact that the size increase required to achieve non-afterburning dash speeds was too large, caused the augmented engine to be rejected. The non-augmented engine chosen, although heavier, allowed greater range over the low-level mission and was therefore selected.

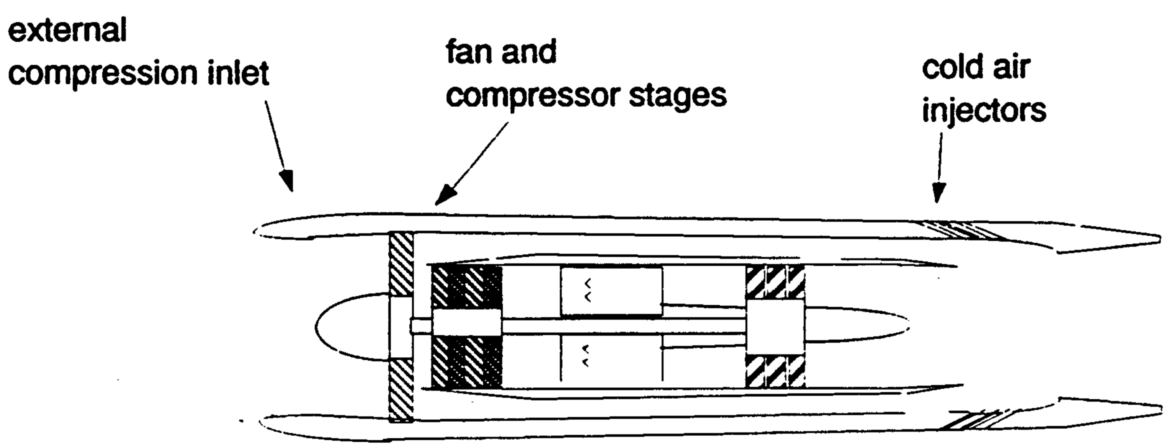
9.2 Engine Placement and Inlets

Engines were placed directly above the wing near the fuselage in order to protect them from small arms ground fire and to reduce foreign object ingestion while using unprepared runways. This location was also selected to avoid gun exhaust ingestion and

subsequent stall when the forward mounted GAU-8A is fired, while canard positioning is designed to force gas flow under the wing and away from intakes. As well as allowing easier access to engine components, the external mounting of the engines allows installation of short inlets with primarily external compression which decreases pressure losses, keeping them lower than 2.8 lbs/ft^2 at sea level conditions (the engine layout is shown in Figure 9.1.).

The placement of the engine exhaust nozzle is 2.2 feet forward of the wing trailing edge in order to reduce IR signature from the ground, and cold air injectors cool exhaust gases in the exhaust nozzle , thereby reducing IR signature even further.

Figure 9.1 Turbofan Engine Diagram

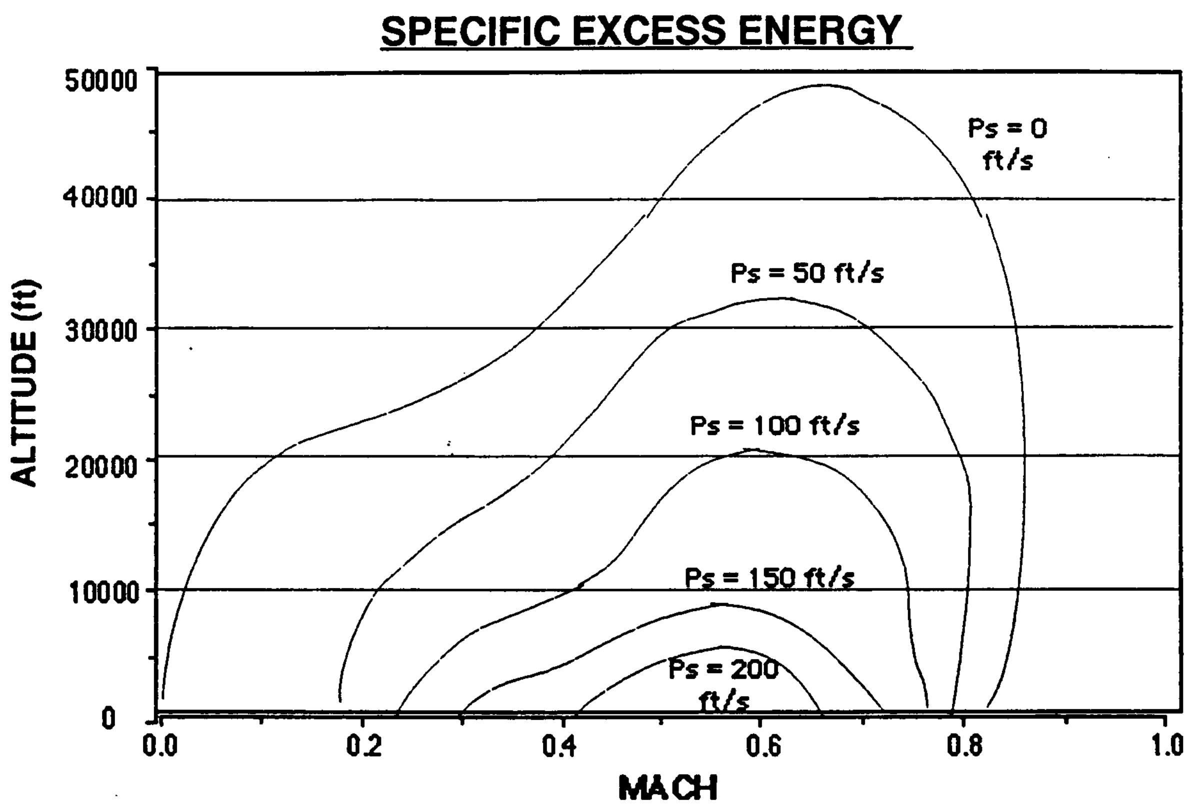


9.3 Engine Installation and Performance

Losses in engine performance due to operation of on-board systems were found to be approximately 188 SHP, with electronics

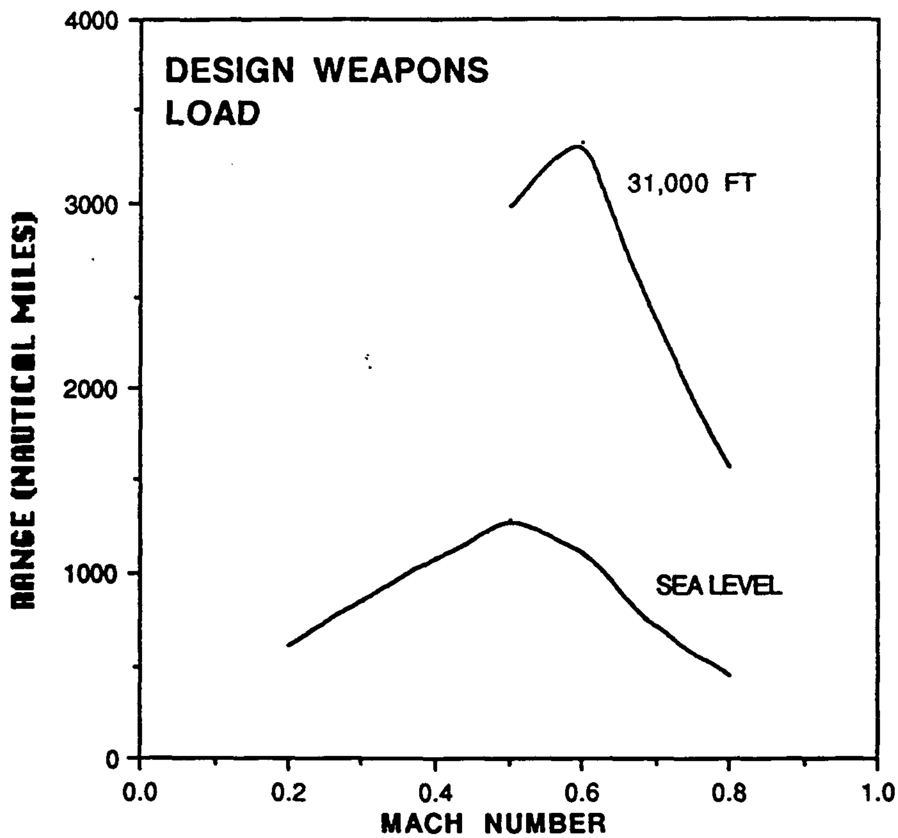
and mechanical systems being relatively small compared to other aircraft. The use of limited electronic flight control and weapons systems, as well as the low air bleed required by the fly-by-wire controls system helps to reduce this value significantly, although many component power requirements could not be determined accurately. With an installed T/W of 0.62 at takeoff, the engine's performance is adequate to achieve the primary mission requirements, while being capable of exceeding them should new situations arise. The maximum level speed at sea level is 520 knots and this speed increases to a maximum of 535 knots at 10000 ft of altitude. Maximum specific excess power of 241 ft/s is achieved at sea level conditions and a Mach number of 0.55. The excess power plot over the aircraft's flight regime is shown (see Figure 9.2.), and the absolute ceiling can be seen at 48000 ft.

Figure 9.2



The aircraft's performance is best at higher altitudes, with the maximum range achieved at an altitude of 31,000 ft and a Mach number of 0.6. At this condition, the specific fuel consumption is at 0.712 Lbm/hr-Lbf, and the throttle setting is at 4/10 of maximum throttle. At this flight condition, total accumulated range with full design payload and no external fuel is 3440 nautical miles. A plot of range vs. Mach number both at sea level and at 31,000 ft is provided in Figure 9.3., and from these plots it can be seen that the *Guardian* can carry the design payload over a range nearly three times further if able to fly at this best altitude and speed.

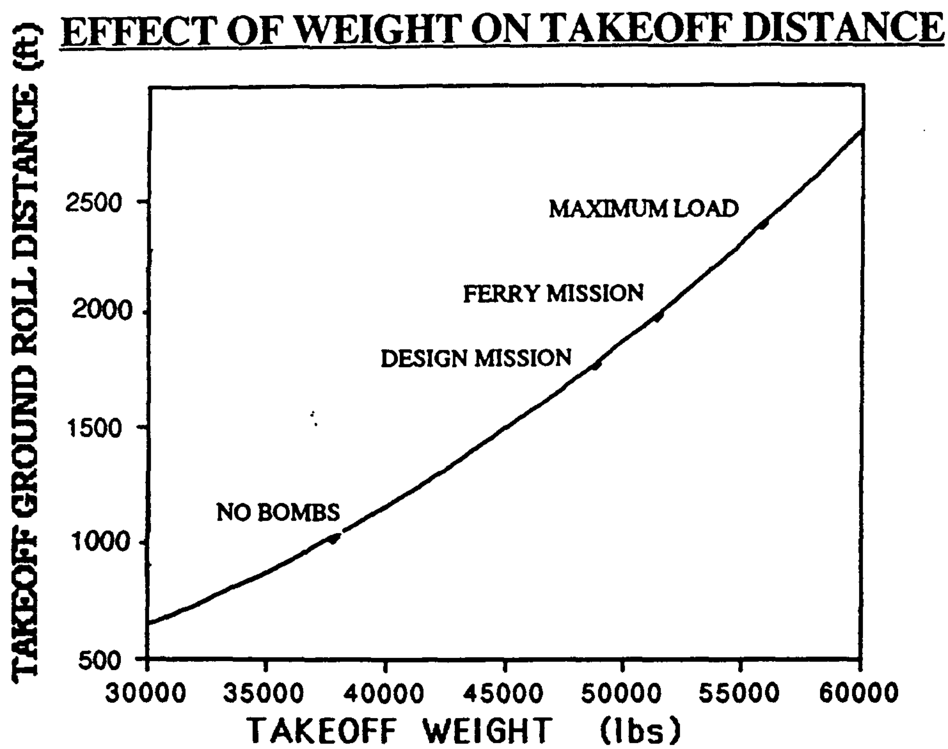
Figure 9.3 Accumulated Range vs. Mach



9.4 Take-off and Landing

The *Guardian* is capable of taking off in a distance of 1784 ft with an external payload of 20 Mk82 bombs (design mission), with takeoff distances changing with aircraft weight as shown (see Figure 9.4.).

Figure 9.4

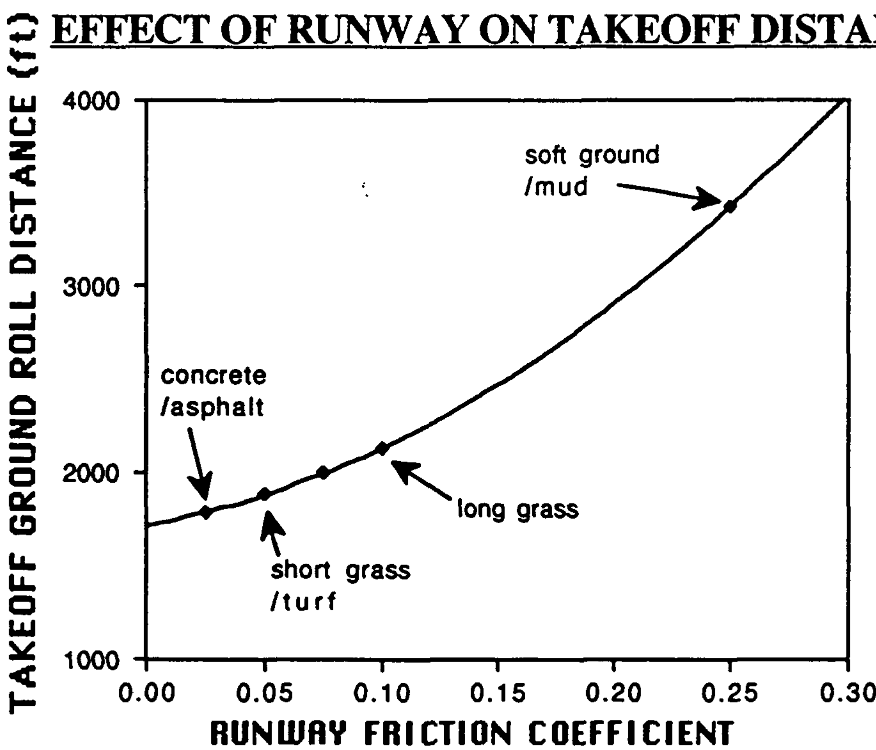


With no external payload, the *Guardian* can lift off in a mere 1036 ft, while a maximum external load of 19,500 lbs requires a ground roll of 2394 ft (higher than the RFP requirement). In order to achieve maximum ferrying distances, external fuel was added to achieve a takeoff distance of 2000 ft. This requirement allows for a maximum of 9,505 lbs additional fuel, which pushes the overall range of the aircraft to 3830 nautical miles (see Section 9.1.4). This greatly exceeds the distance requirements set out in the RFP for the alternative ferry mission.

The effect of using an unprepared runway is to increase the distance required for takeoff, as wheel frictional forces reduce aircraft acceleration capability. When the *Guardian* is loaded with design mission armament, it can take off in the required 2000 ft

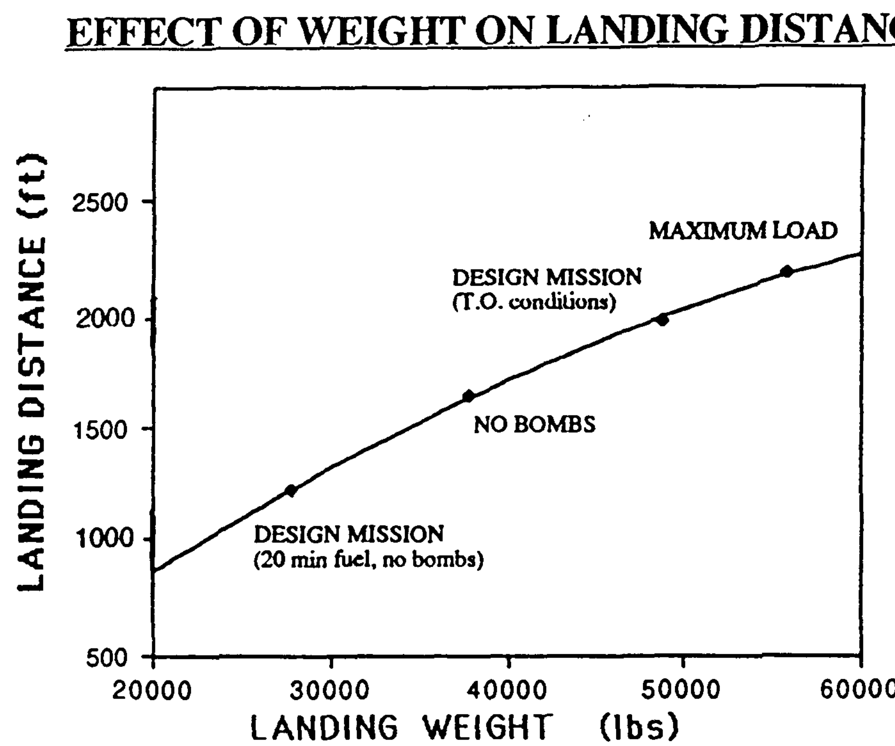
runway length for runways with frictional coefficients up to 0.076. This value corresponds to a medium-length grass strip with hard ground. A plot of takeoff distance with runway conditions is shown in Figure 9.5 for design mission takeoff conditions with flaps down.

Figure 9.5



The total distance required for landing is also heavily dependent on aircraft weight. For a fully loaded landing (design mission stores), the minimum landing distance is 1975 ft, which satisfies the RFP requirement of less then 2000 ft. This value decreases further, as shown in Figure 9.6, if landing without external payload.

Figure 9.6



Ground roll landing distances decrease to 1644 ft with no external weapons and full internal fuel, and to as low as 1228 ft with no bombs and 20 minutes of fuel remaining (design mission condition). The maximum landing distance required by the *Guardian* (with 19,500 lbs external payload and full internal fuel) is only 2182 ft. These low ground roll distances are achieved by deployment of spoilers and wheel brakes coupled with extended airbrakes. The use of airbrakes with the spoilers increases the Cd,o to 0.58, which effectively reduces the landing distances to within the required limits.

9.5 Best Altitude and Speed

The maximum range of the *Guardian* is achieved at altitude of 31,000 ft, and a Mach number of 0.6. This cruising condition was found by determining the range variation with mach number at various altitudes and determining the maximum range point. Figure 9.7 shows the maximum range capability as a function of altitude, and the best altitude can be seen at 31,000 feet. At each altitude, range tends to increase with increased Mach number to a maximum point (about M=0.5 to 0.7), and then drops off at high Mach numbers (see Figure 9.3). The Mach number for maximum range as a function of altitude is shown in Figure 9.8. These values represent the aircraft with full external stores and 60% internal fuel. Preliminary estimates show that the ideal cruising altitude does not change significantly as fuel is burned.

Figure 9.7. Effect of Altitude on Maximum Range

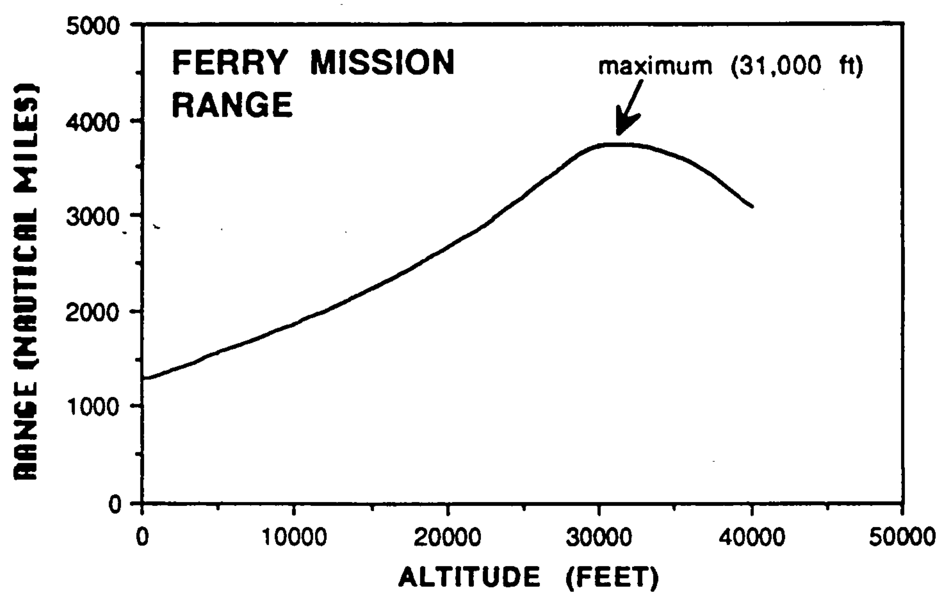
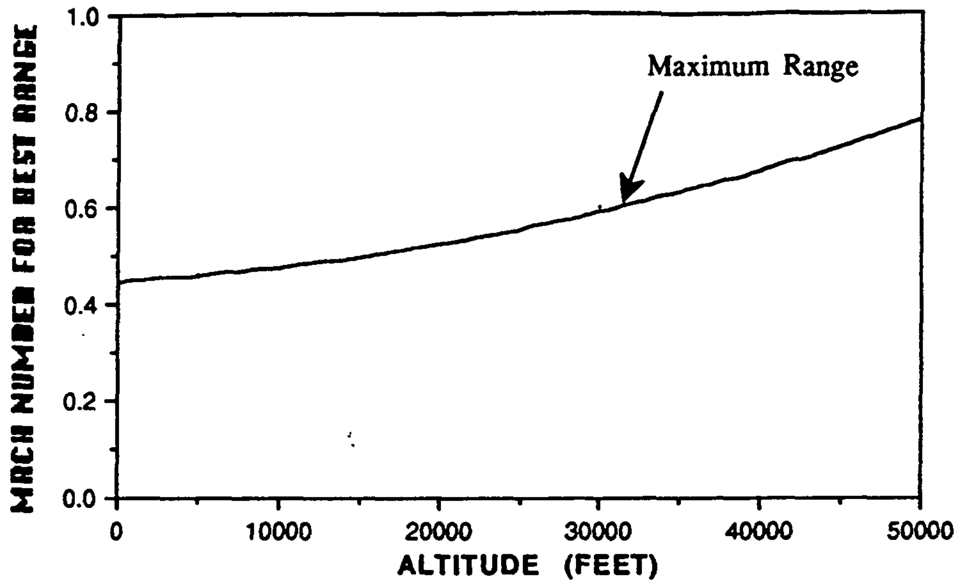


Figure 9.8 Best Mach Number vs Altitude



9.6 Range vs. Payload

The range of the *Guardian* depends greatly on the weight at takeoff as well as the amount of fuel stored. The decrease in overall range as a function of weight is shown in Figure 9.9. with full internal fuel (8553 lbs) and no external fuel, and the reduction in range is clearly seen with increased weight. The addition of external fuel also increases the aircraft's takeoff weight, but increases the range greatly, as expected. Figure 9.10. shows the effect on the alternative ferry mission (no bombs) of increased weight for fuel.

Figure 9.9 Range vs. Take-off Weight

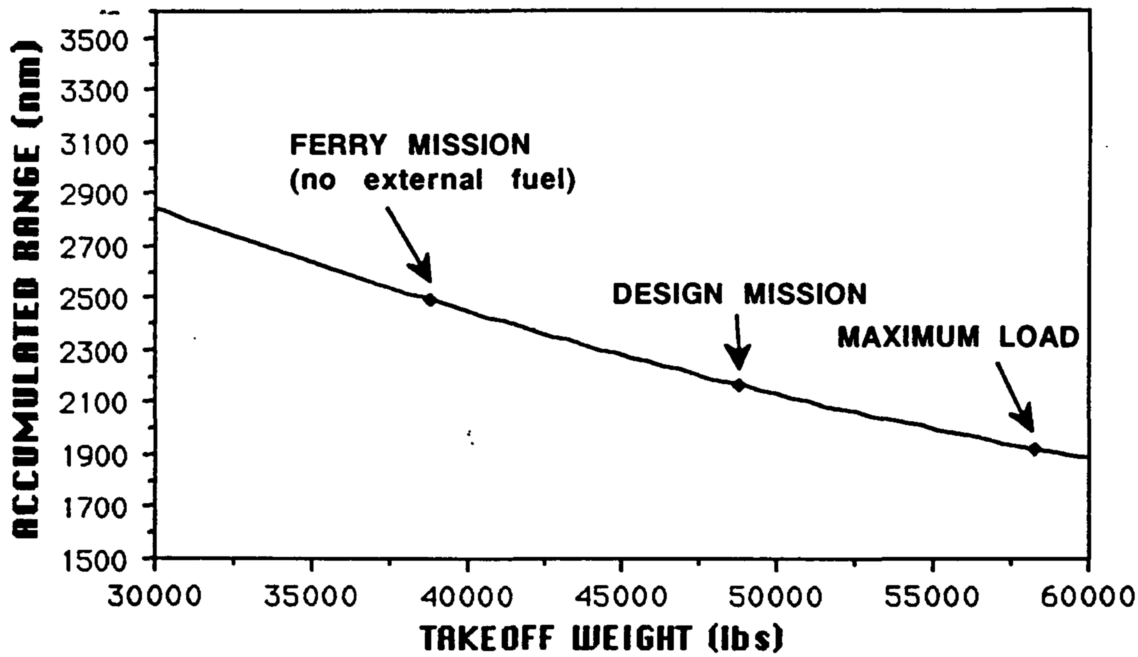
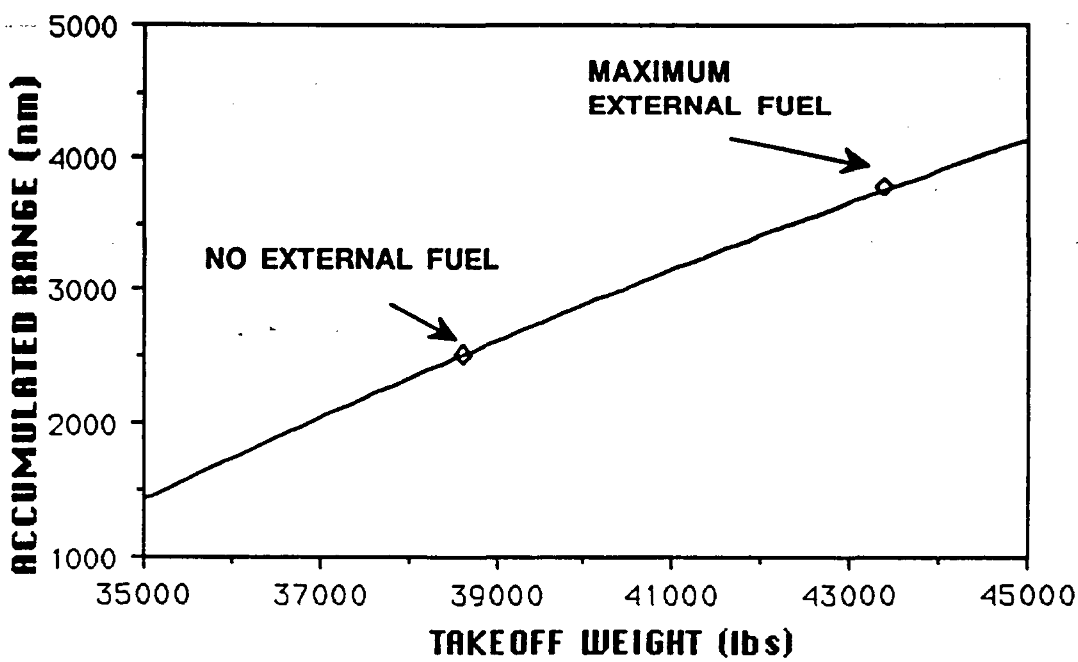


Figure 9.10 Effect of Fuel Weight on Ferry Range



9.7 Mission Performance

9.7.1 Low Level Mission (Design Mission)

The *Guardian* is designed primarily to achieve the low level attack mission set forth in the RFP (see Section 2.0), and preliminary analysis shows that it will perform this mission quite well. Table 9.1 lists the total aircraft weight at the end of each mission step, as well as the thrust specific fuel consumption achieved.

Table 9.1 Weight Change Over Design Mission

	WEIGHT	Cj
INITIAL WEIGHT	48753	
WARMUP	48372	0.975
TAXI	48090	0.975
TAKEOFF	47462	3.9
ACCELER	46951	1.02
DASH (250NM)	44532	0.82
COMBAT	33186	0.91

DASH (250NM)	30104	0.82
LANDING	30104	

21.4 MIN
RESERVE

Values were found using actual TSFC values supplied by the engine manufacturer, and accumulated range includes acceleration and dash distances. Fuel consumption in the combat phase includes two combat passes, each consisting of a 360 degree 4.5 g turn and 4000 ft energy increase. A total initial fuel weight of 8593 lbs was required, which allowed for all mission objectives, while allowing 21.4 minutes of reserve fuel at landing.

9.7.2. High-Low-Low-High Mission

The alternative attack mission (high-low mission) can also be performed excellently by the *Guardian* , with a mission profile as shown in Table 9.2. Altitude for both high altitude cruise portions is assumed to be the best altitude for this aircraft (31,000 ft), while climbing conditions are assumed at maximum excess power at each altitude. The climb to altitude takes only 4.3 minutes, and Cj is assumed to vary linearly over the climb as shown. The acceleration time is calculated to only Mach 0.55, as this is the best climb speed at sea level.

Table 9.2 Weight Change Over High-Low Mission

	WEIGHT	Cj	
INIT. WEIGHT	48757		
WARMUP	48372	0.975	
TAXI	48090	0.975	
TAKEOFF	47462	3.9	
ACCEL.	46858	1.01	
CLIMB (30K)	46613	(.61-.712)	
CRUISE(150)	46122	0.712	
LOITER	45772	0.88	(8.4 MINUTES)
DASH(100)	44911	0.82	
COMBAT	31780	0.91	
DASH(100)	30688	0.82	
CLIMB (30K)	30519	(.61-.712)	
CRUISE(150)	30011	0.712	
LANDING	30011		

20 MIN RESERVE

Loiter time was determined by working backwards from the required fuel reserves, fuel required to return to the airbase, and the fuel for both sea level dashes and combat passes. The maximum allowable time to loiter at this phase is 8.4 minutes, which allows for 20 minutes of reserve fuel. The dash in was assumed to be at best speed at sea level (M = 0.6) and combat passes were assumed the same as the design mission. Climb and cruise back to base were assumed the same as outgoing conditions. This entire mission is performed assuming internal fuel only, and no firing of gun or missiles.

9.7.3. Ferry Mission

The alternative ferry mission capabilities of the *Guardian* are well above the necessary levels to achieve RFP requirements. The *mission requirements can be met with full internal fuel and only 786* lbs of external fuel. The weight analysis of the ferry mission is shown in Table 9.3. for this case of minimum required fuel.

Table 9.3 Weight Change Over Ferry Mission

	WEIGHT	Cj
INIT. WEIGHT	38305	-
WARMUP	38006	0.975
TAXI	37590	0.975
TAKEOFF	37262	3.9
ACCELER	36889	1.01

CLIMB (30K)	35266	(.61-.712)
CRUISE(1500)	30011	0.712
LANDING	30011	

20 MIN RESERVE

Again, the Mach number during climb is assumed at best climb condition, and altitude and speed at cruise assumed at 31,000 ft and Mach = 0.6. For longer ferry missions, the *Guardian* can carry as much as 7800 lbs of external fuel (still allowing takeoff in 2000 ft), which extends the ferry range to over 3800 nautical miles.

9.8 Combat Performance and Maneuvering

The *Guardian* is capable of 5.1 sustained G's in combat with a velocity of 457 knots, which correspondingly gives it a turn radius of 2464 ft and a turn rate of 17.86 degrees per second. In order to achieve the increased energy requirement of 4000 ft, all excess energy is assumed to be used in climbing (this climb takes 19.18 seconds). The aircraft can simultaneously make the 360 degree turn required in 20.16 seconds at maximum turn rate, which gives the *Guardian* a re-attack time of 20.16 seconds. This value is well under the required time of 25 seconds required in the RFP. Because the weight decreases after the second bomb drop, the time to turn 360 degrees decreases during the second combat phase to only 19.21 seconds. These values represent the *Guardian* with 50% internal fuel as well as full gun ammunition and both AIM-9L missiles.

Acceleration from Mach 0.3 to 0.5 at sea level (198 knots to 331 knots), requires 16.79 seconds. This assumes full engine throttle over this time period, and results in an average excess thrust of 16,208 lbs and an average acceleration of 13.3 ft/s^2 over the acceleration time (engine lag time has not been accounted for). This value exceeds the RFP requirement of 20 seconds, and a table of performance values is presented in Table 9.4. which compares RFP requirements to the *Guardian* 's estimated performance characteristics.

Table 9.4 Aircraft Performance

	RFP requirement	The *Guardian*
TAKEOFF DISTANCE		
(DESIGN MISSION)	<2000 ft	1784
(HIGH-LOW MISS)	<2000 ft	1784
(FERRY MISSION)	<2000 ft	1145-2000
LANDING DISTANCE		
(DESIGN MISSION)	<2000 ft	1235
(HIGH-LOW MISS)	<2000 ft	1228
(FERRY MISSION)	<2000 ft	1228

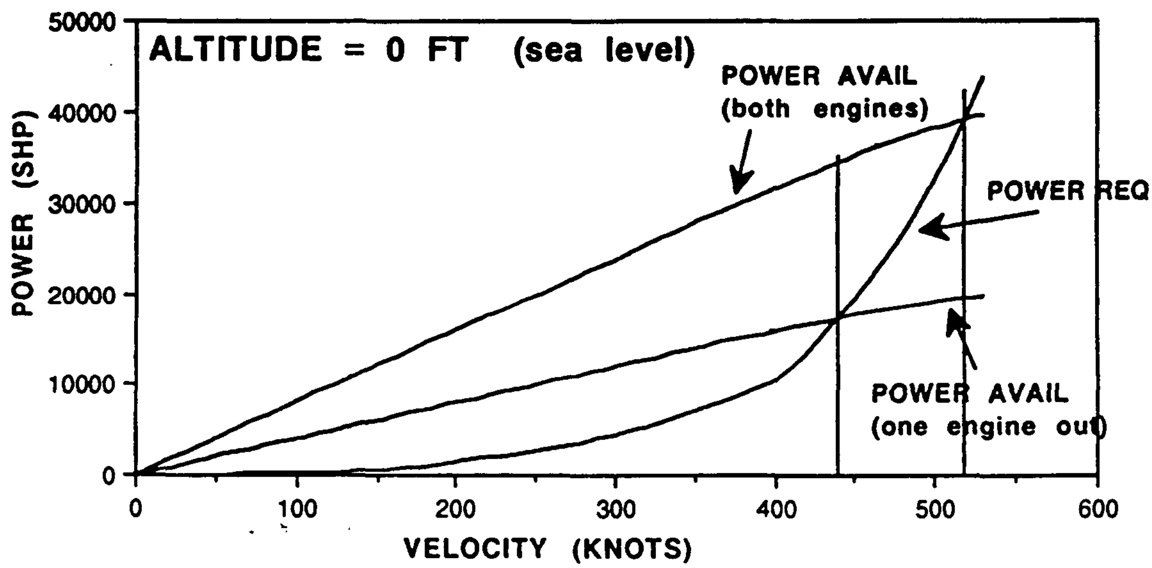
LOITER TIME		
(DESIGN MISSION)	>20 min	21.4 min
(HIGH-LOW -I)	/ /	8.4 min
(HIGH-LOW -II)	>20 min	20 min
FERRY RANGE	1500nm	1500-3130nm
ACCELERATION		
(MACH 0.3-0.5)	<20 sec	16.19 sec
SUSTAINED G'S	>4.5	5.1
INSTANT. G'S	>6.0	6.2
RE-ATTACK TIME	<25 sec	21.16 sec

9.9 Engine Out Performance

The performance of the *Guardian* after the loss of one engine, by weapons hit or otherwise, is quite good, with capabilities of completing many mission objectives remaining intact. A titanium plate separates the two engines, and therefore engine fire or explosion will is unlikely to damage the remaining engine. The maximum speed that can be achieved at sea level is reduced to 440

knots from 520 knots with both engines (see Figure 9.11.). Also, maximum rate of climb is reduced to 84 ft/s at a Mach number of 267 knots from a maximum of 241 ft/s with both engines available, which allows the *Guardian* to climb to an effective ceiling of 22,000 ft and perform low level and high-low attack missions adequately. Although all fuel can be routed to the functioning engine, analysis shows a decrease in range of approximately 40% after engine out, which is due to the fact that with the single engine operating, a much lower speed and higher TSFC is required to achieve maximum range.

Figure 9.11 Power vs. Velocity With One Engine Out



9.10 Performance Flexibility

Aircraft performance was analyzed over a range of various missions to determine the flexibility of this design, and performance characteristics were found to be excellent for high load missions,

with capabilities of carrying as much as 19,500 lbs of external weapons at a range of 175 nautical miles in the design mission, and can fly a ferry mission in excess of 3800 nautical miles with two 600 gallon external fuel tanks while flying at best altitude and velocity. These values were calculated using estimated fuel losses during the warm-up, taxi, and takeoff, and maintaining a 20 min fuel reserve. The ability of the *Guardian* to take off from unprepared strips with minimum runway lengths, as well as its flexibility in mission performance make it ideal for combat situations where adaptability is a necessity.

10.0

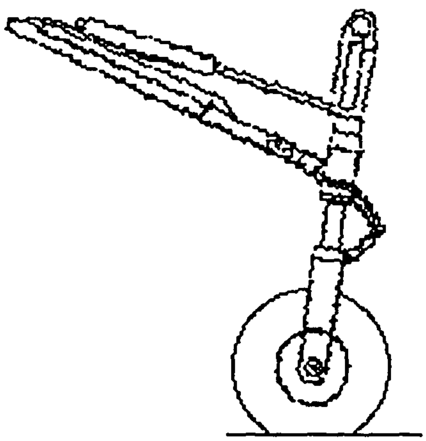
LANDING GEAR

A conventional retractable, tricycle type landing gear is employed. Although retractable gear is more costly and increases the weight of the aircraft, it is necessary in order to decrease the drag. Tricycle gear was chosen because it is widely used and well proven on fighter type aircraft. Main gear similar to the gear of the F-16 in mounting and retraction was chosen to save on cost while still being able to meet the criteria of the *Guardian* . Type III tires were chosen for both the nose and main gear because they are designated as a low pressure tires. Low pressure tires enable the aircraft to land on unprepared surfaces.

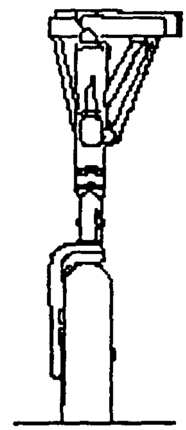
10.1 Nose Gear

The nose gear as shown in Figure 10.1 is placed such that it retracts hydraulically forward into the front area of the cockpit. It is slightly off-center from the centerline of the fuselage because the main barrel of the gun is placed along the centerline to avoid large yaw moments when firing.

Figure 10.1 Nose Gear



Side View



Front View

The following data is for the nose gear tire:

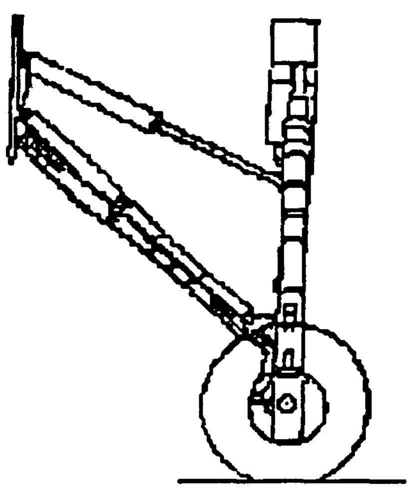
Number of tires/strut	1
Weight	47 lbs
Maximum Static Load	6300 lbs
Tire Size (WxDo)	11"x31"
Ply Rating	8
Pressure	45 psi
Maximum Speed	120 MPH

10.2 Main Gear

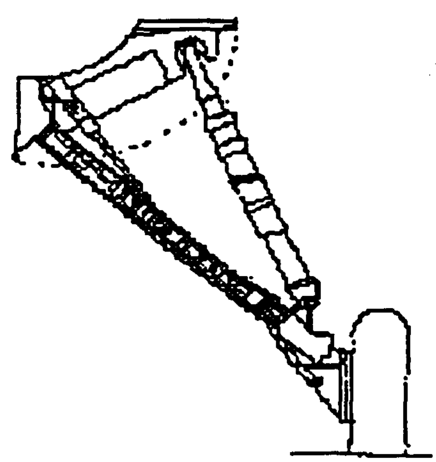
The main gear shown in Figure 10.2 is located at the quarter chord of the wing and hydraulically retracts aft with a sink speed of 10 feet per second into the fuselage in a three step process as shown in Figure 10.3. The main gear rotates inboard and then upward

into the fuselage. During the first rotation the wheels rotate to place them vertically side by side before rotation into the fuselage. By utilizing the fuselage space for storage of the main landing gear instead of the wing, less structure for the wing is needed. The tires are placed 7.4 feet from the centerline of the fuselage to meet the guidelines for lateral tip-over . To meet the guideline for longitudinal tip-over , the main gear is located 28.2 feet behind the nose of the cockpit. The placement of the main gear also allows a 20.7 degree longitudinal ground clearance which provides more than the minimum of 15 degrees used as a guideline.

Figure 10.2 Main Gear



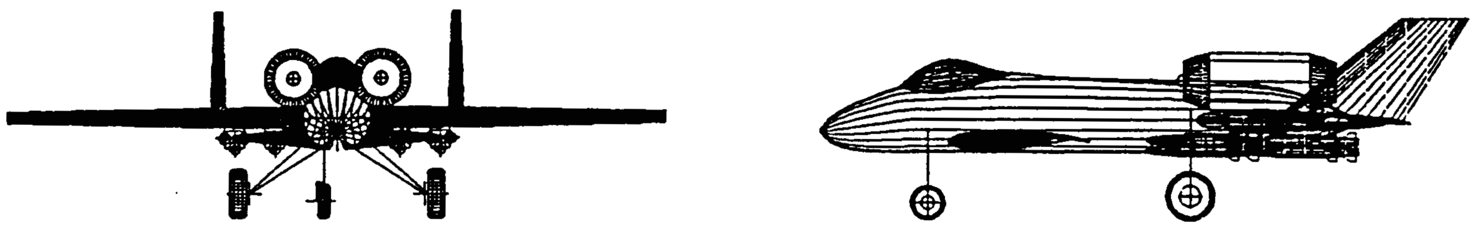
Side View



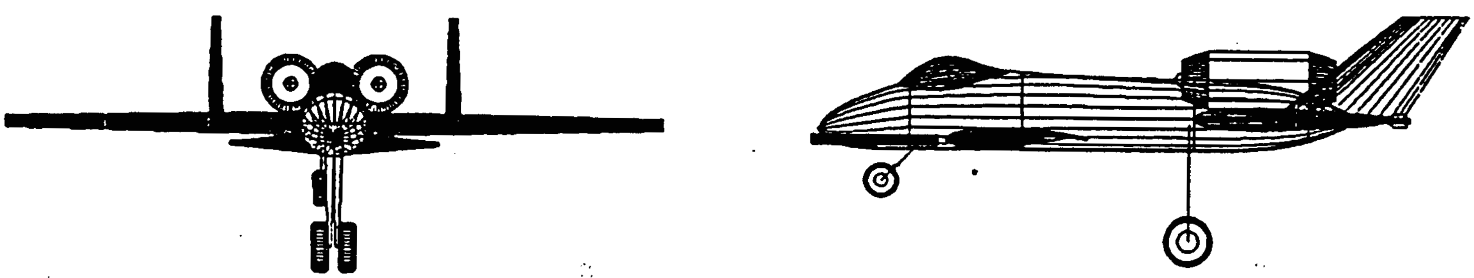
Front View

The following data is for the main gear tires:

Number of tires/strut	2
Weight	130 lbs
Maximum Static Load	24000 lbs
Tire Size (WxDo)	15.05"x44.30"
Ply Rating	16
Pressure	105 psi
Maximum Speed	160 MPH



Landing Gear Extended



Landing Gear Rotation

Landing Gear Retracted

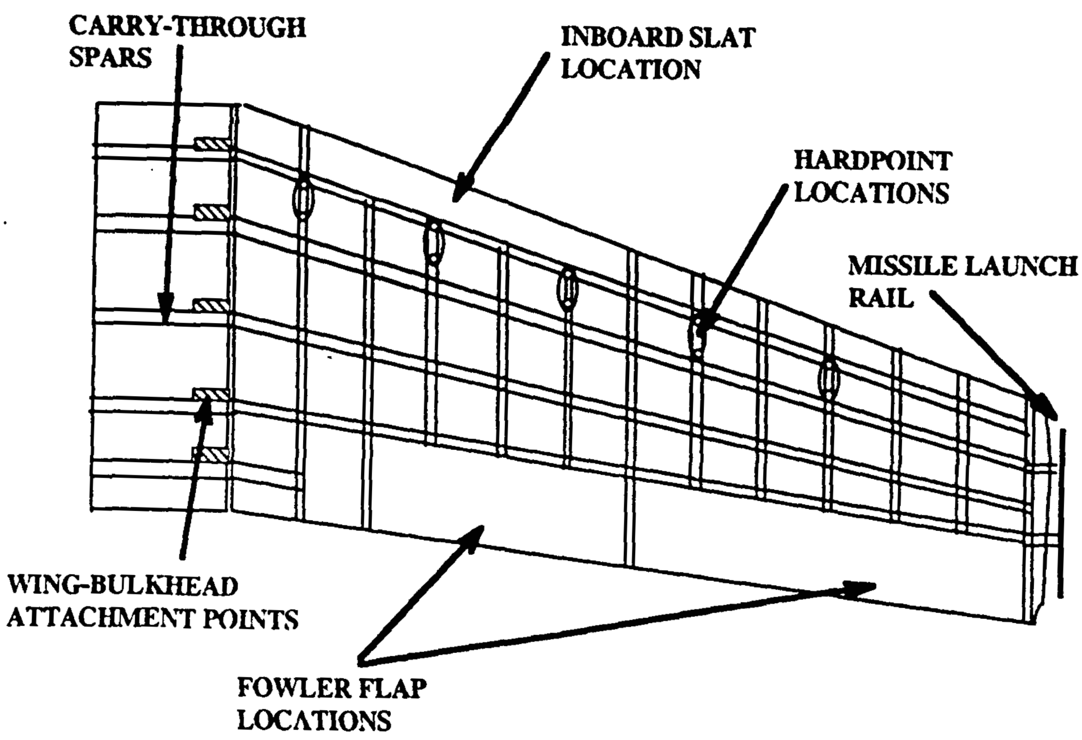
Figure 10.3 Landing Gear Retraction Sequence

11.0

STRUCTURAL LAYOUT

The structural design of the *Guardian* consists primarily of a four spar wing structure integrated with the aft fuselage, engine support structure, and vertical tails. As this portion of the aircraft contains the majority of loading components, it contains a large portion of the structural weight. In the forward fuselage sections, longerons carry the aerodynamic loads applied through the canard, as well as supporting the massive loads of the forward mounted GAU-8A 30mm gun, ammunition, and feed lines. The lower longeron / bulkhead structure contains two additional longerons along the barrel centerline to transmit the 9000 lb force of gun firing through to the aft structural core.

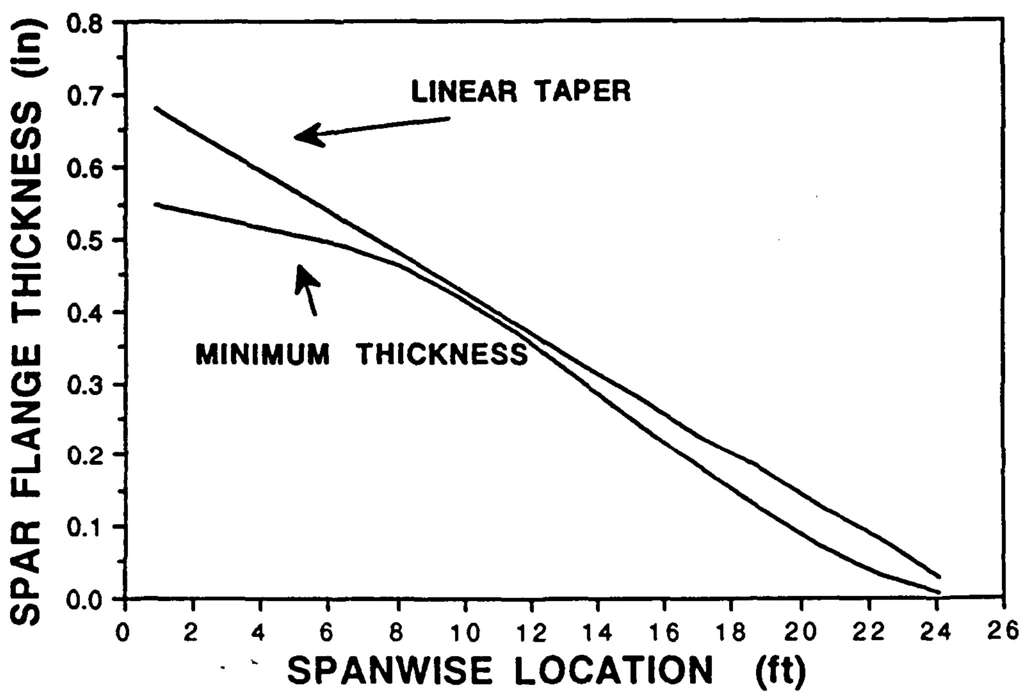
Figure 11.1 Wing Structural Design



11.1 Wing Structure

The wing structural layout is shown in Figure 11.1., and in order to reduce wing weight, each of the four support spars is tapered, to provide stresses low enough to allow for a 1.5 factor of safety, while limiting unnecessary material. Using aluminum 2014-T6, and an I-beam spar cross section, the minimum thickness at each point was found to vary non-linearly over the wing span (see Figure 11.2.).

Figure 11.2. Spar Thickness vs. Spanwise Location



However, to reduce complexity and cost in the manufacturing process, a linearly tapered thickness was chosen which satisfied all stress requirements with a minimum of excess weight. Loading conditions for a

positive loading of 11.25 G's and a negative loading of 4.5 G's have been analyzed with a variety of wing loads, which correspond to the structural limits required by the RFP (+7.5 and -3.0 G's), with a safety factor of 1.5. A comparison of various load cases showed that maximum stresses occurring at full external design payload and a positive load factor of 11.25 G's. The maximum stress case for the design mission as well as the corresponding shear and moment diagram are shown in Figures 11.3-11.5., and the structure is capable of supporting a full payload of 19,500 lbs over all twelve hardpoint locations, with a maximum safe loading of 9.1 G's. This weapons loading is achieved by distributing the external weapons over the entire wing span (see Section 8.0), which limits stress concentrations and lowers the moments occurring in the inboard spar sections (thereby reducing structural weight).

Figure 11.3.

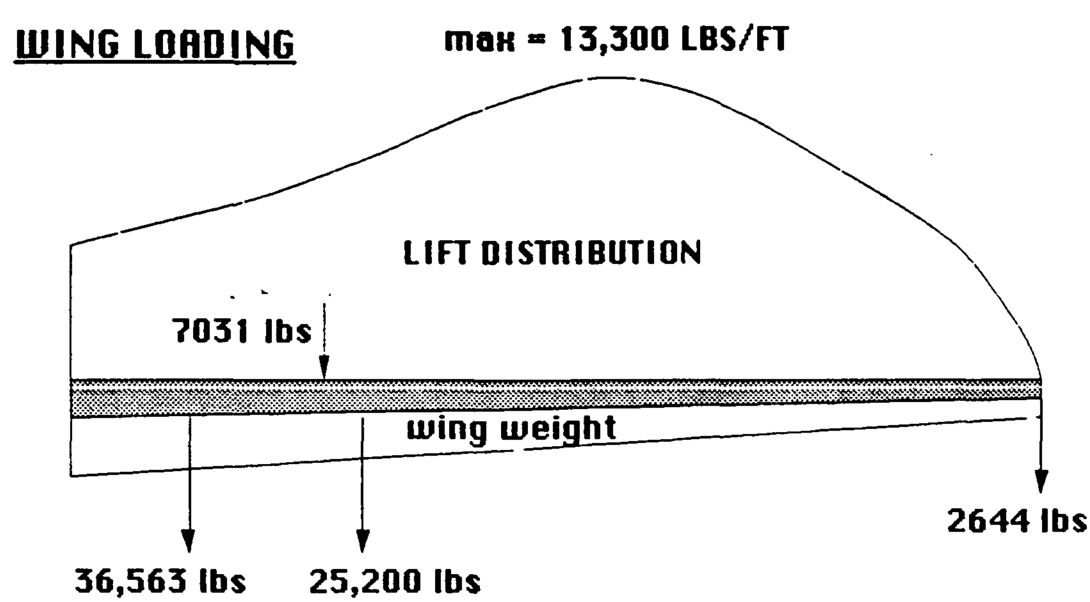


Figure 11.4.

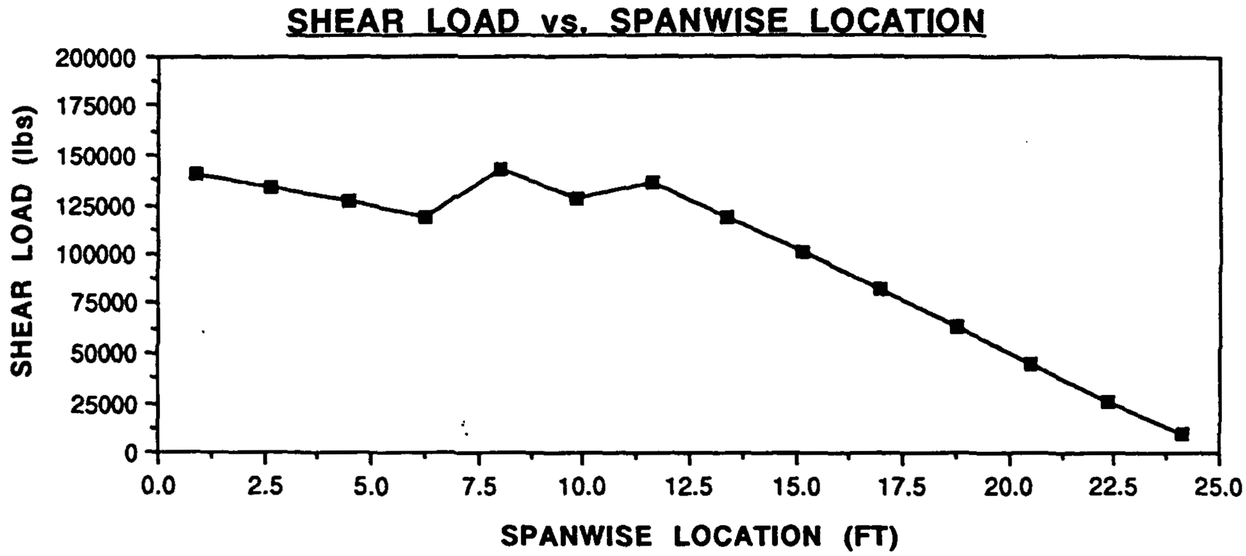
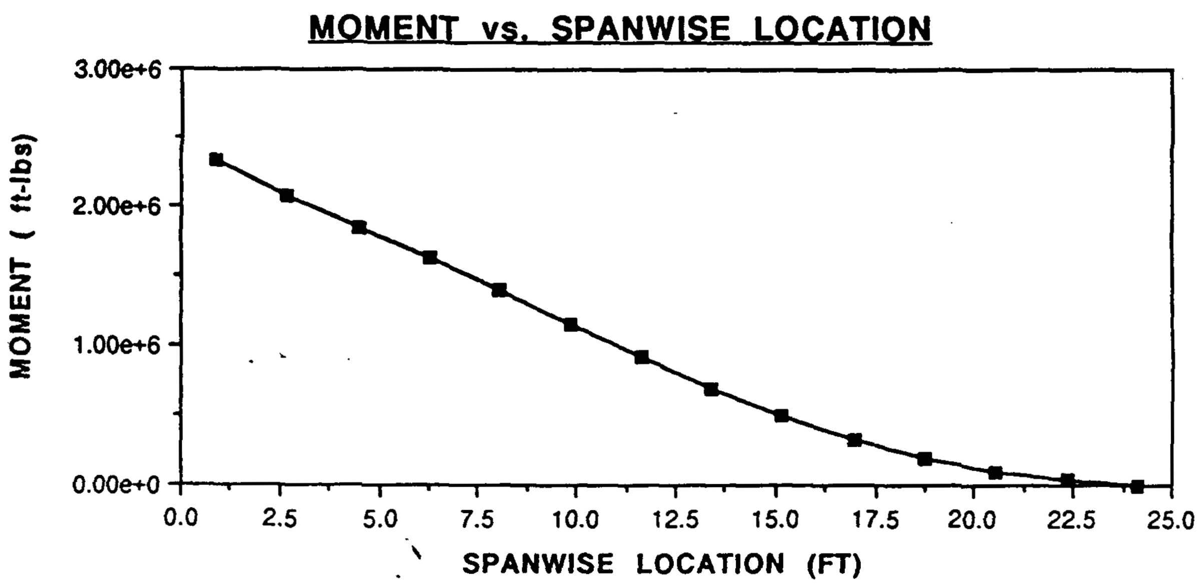


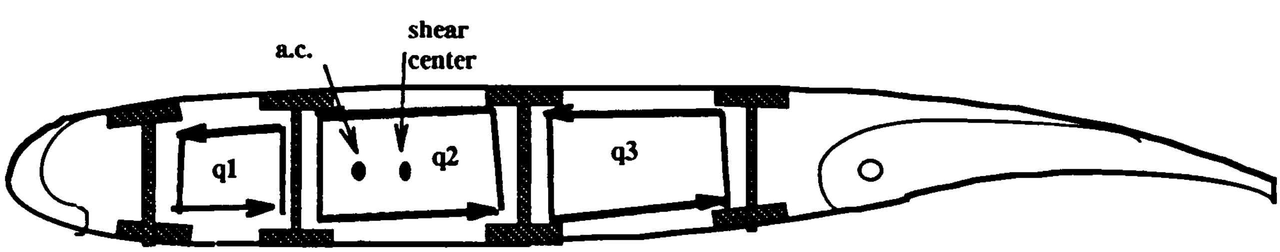
Figure 11.5



These shear forces and moments were determined by splitting the wing semi-span into 15 sections, and determining the net forces acting on each. The shear and moment at each position was then determined by numerically integrating these forces to each location. The maximum stresses at each position were then found using standard methods for cantilevered beams, with maximum normal stresses found at the upper and lower I-beam edges and shear stresses being maximum at the web center. As expected, maximum moment occurred at the inboard end of the wing, while the maximum shear load was found to be at a position 8.4 ft outboard (see Figure 11.5.).

The torque box is designed to allow for acceptable torsional stress distributions while limiting net torques at high wing loading. This is accomplished by placing the forward spars nearer the leading edge which moves the shear center nearer to the aerodynamic center of the wing as shown in Figure 11.6. By doing this, the twisting caused by high G loading

Figure 11.6 Shear Center

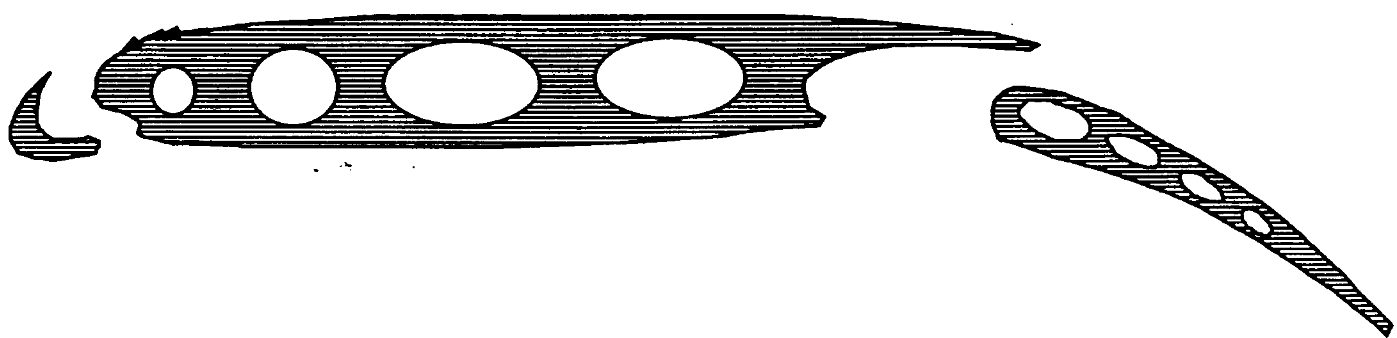


is reduced and the structure and weight required in the total wing structure is reduced to lower than 4000 lbs. The shear center was determined by finding the shear flow in each of the three sub-sections

and determining the chordwise position at which a vertical shear loading results in no twisting moment. The wing skin loading capabilities were incorporated by adding lumped masses at the midpoint of each skin section. Maximum torsional stresses were found to be at the web midpoint of both the forward and aft spars. The effect of wing flaps and slats tends to be to move the aerodynamic back along the section, which moves it closer to the shear moment and decreases twisting moments further. However, strong pitching moments occurring during flap deployment counteract this effect considerably.

The wing skin is made up of 0.15 inch thick Al 7075 - T6, and are fixed with rivets along the rib edges and spars. The rib structure for a typical spar is shown in Figure 11.7. (at flap and slat location), and each rib 0.25 times the spar flange thickness. This allows ample structure to transmit the aerodynamic loads on the skin through to the wing spars without skin buckling or rib failure.

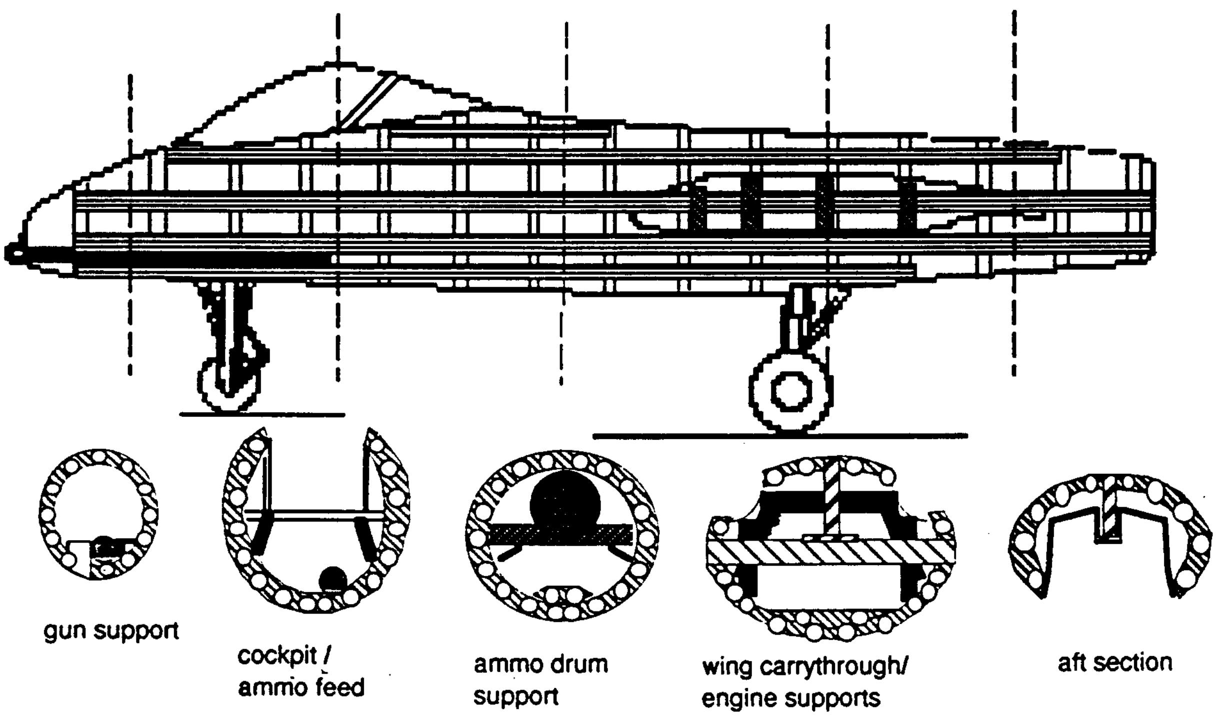
Figure 11.7 Wing Rib Layout



11.2 Inboard Structure

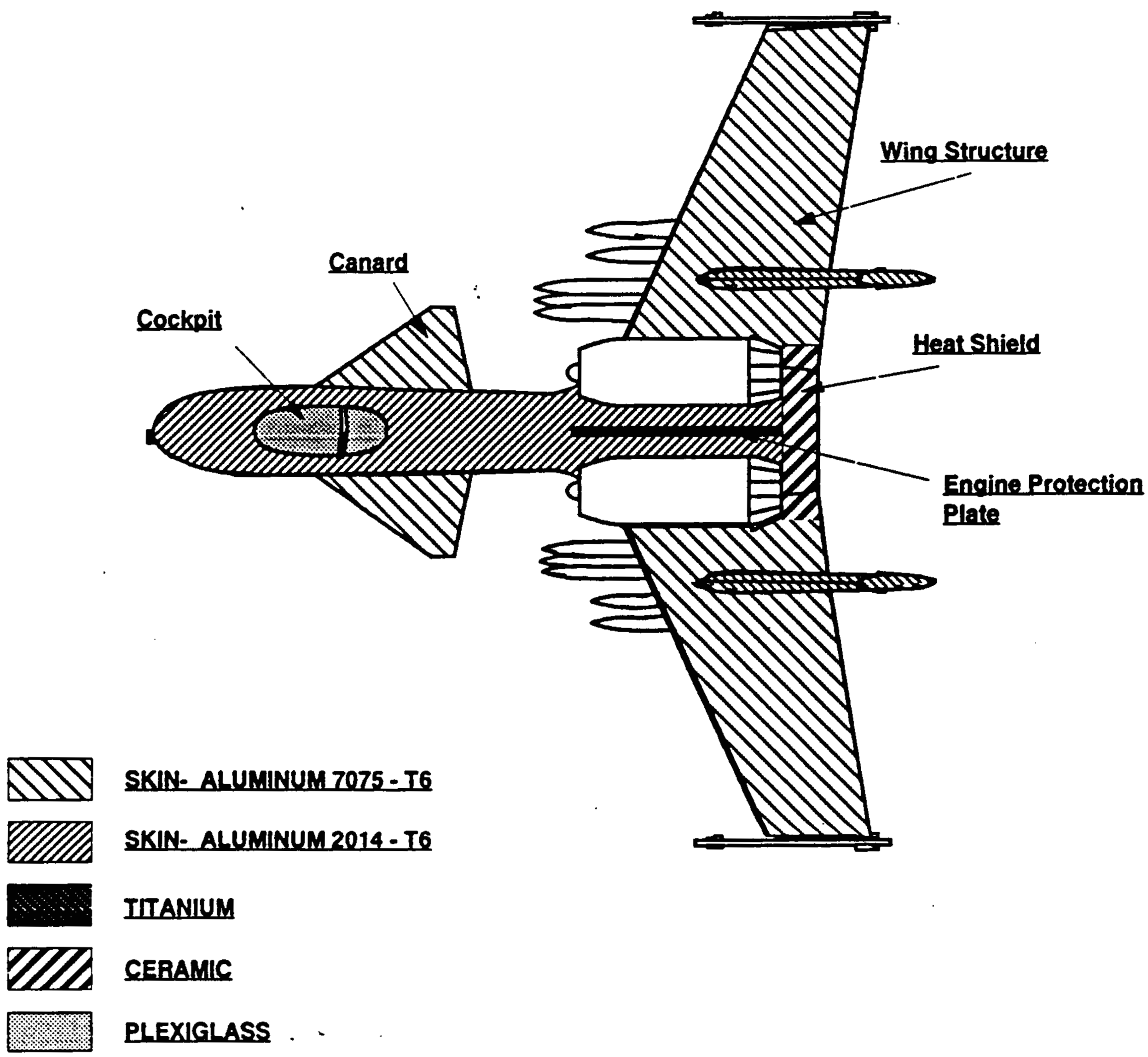
The fuselage layout contains two major support structures at the forward and aft ends as shown (Figure 11.8.). The forward structure supports the 30mm gun and ammunition as well as the cockpit, electronics, and the forward fuselage fuel tank, and contains support beams which support the ammunition tank above the canard control systems and actuators.

Figure 11.8 Fuselage Layout



Pressure bulkheads fore and aft of the cockpit allow for pressurization, while giving additional support to canard carry-through spars and front landing gear. The aft section is made up of the wing carry-through and bulkhead attachment points as well as the aft fuel tank and engine supports. The canard structure is made up of a three spar, six rib layout with two carry through spars to increase rigidity, while reducing overall structural weight. A diagram of the materials used for the *Guardian* is provided (Figure 11.9.). The absence of composite materials is due to the inherent high costs of manufacture, as well as the higher risks of failure after gun or missile hits than with conventional materials. The durability of aluminum, even after partial breakdown of structural integrity, makes it the ideal choice for the CAS role aircraft.

Figure 11.9 Materials Selection



12.0 COMPONENT WEIGHTS AND C.G. LOCATIONS

12.1 Weight and Balance

Most of the component weights for this aircraft were estimated using empirical relations. The pilot weight and the weight of the stores were specified in the RFP. The weight of the engines were calculated from propulsions data for a turbofan engine supplied by General Dynamics. The weight breakdown and C.G. locations of each component are listed in Table 12.1 and the locations are shown in Figure 12.1 .

The fuel and weapons were situated as close to the C.G. as possible to limit the C.G. travel during a mission when the fuel is burned or weapons are dropped. The landing gear was also placed to meet longitudinal and lateral tip-over criteria. A C.G. excursion diagram for the low level mission is shown in Figure 12.2. The fuselage station is measured from the nose of the aircraft. From this figure it can be shown that the C.G. travel for this mission is 21.3 inches or 17.6 % of the mean average chord.

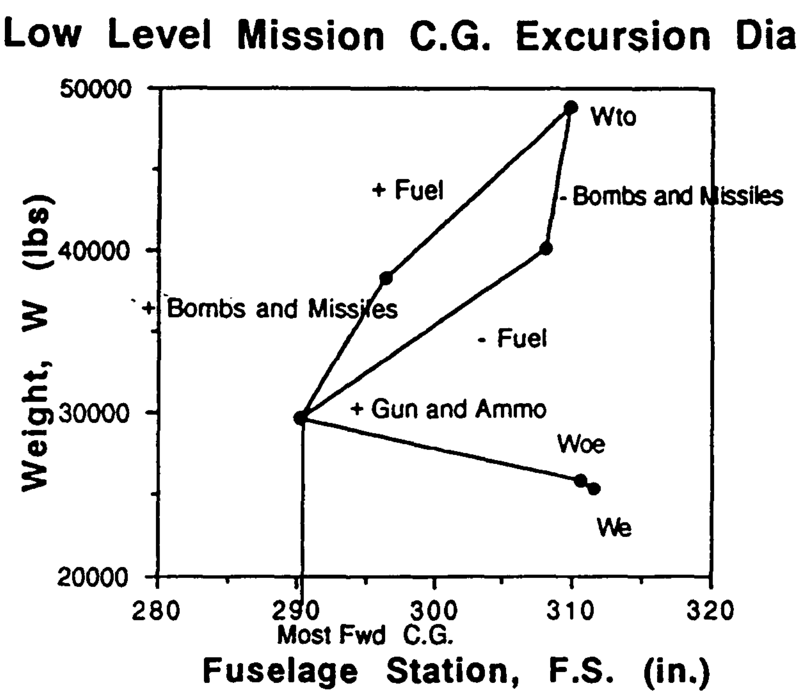


Figure 12.2

Table 12.1 Component Weights and C.G. Locations

	Component	Weight (lb)	F.S. (ft)	W.L. (ft)	W.S. (ft)
1	Wing	3956.6	44	14.8	0
2	Canard	380.8	26	13.0	0
3	Vertical Tails	672.4	48.4	19.0	0
4	Nacelles	1512.5	42.4	17.5	0
5	Fuselage	3804.8	28.0	14.8	0
6	Nose Gear	329.1	18.75	11.4	1.0
7	Main Gear	1316.4	38.73	12	0
8	Engines	7200	42.4	17.5	0
9	Fuel System	389.2	38	15.5	0
10	Eng. Start System	576	38	15.5	0
11	Oil and Cooling	288	38	15.5	0
12	Flight Controls	706.8	18	16	0
13	Electrical System	505.5	27.25	15.8	0
14	API	223.7	23	15.5	0
15	Hydraulics	310	29	16.1	0
16	Oxygen	16.9	19.5	16	0
17	Flt. Test Inst.	150	17.5	15.7	0
18	APU	350.4	48	15	0
19	Armament	210.5	42.4	17.5	0
20	Furnishing	224.5	20	15.7	0
21	IAE	1009.3	28	18.5	0
22	Auxilliary Gear	255.3	29.5	14.0	0
23	Pilot	225	20	15.7	0
24	Fuel	8550	38	16	0
25	Ammunition	2106	28	14	0
26	Missiles w/ racks	470	46	14.5	0
27	Trapped Fuel/Oil	244.93	42.4	17.5	0
28	Gun	1840	18.75	13.3	0.75
29	Bombs with racks	6498	37.5	14	0
30	Bombs with racks	4478	39	14	0
	Take-off Weight	48753			
	CG Location		36.5	15.3	.0350

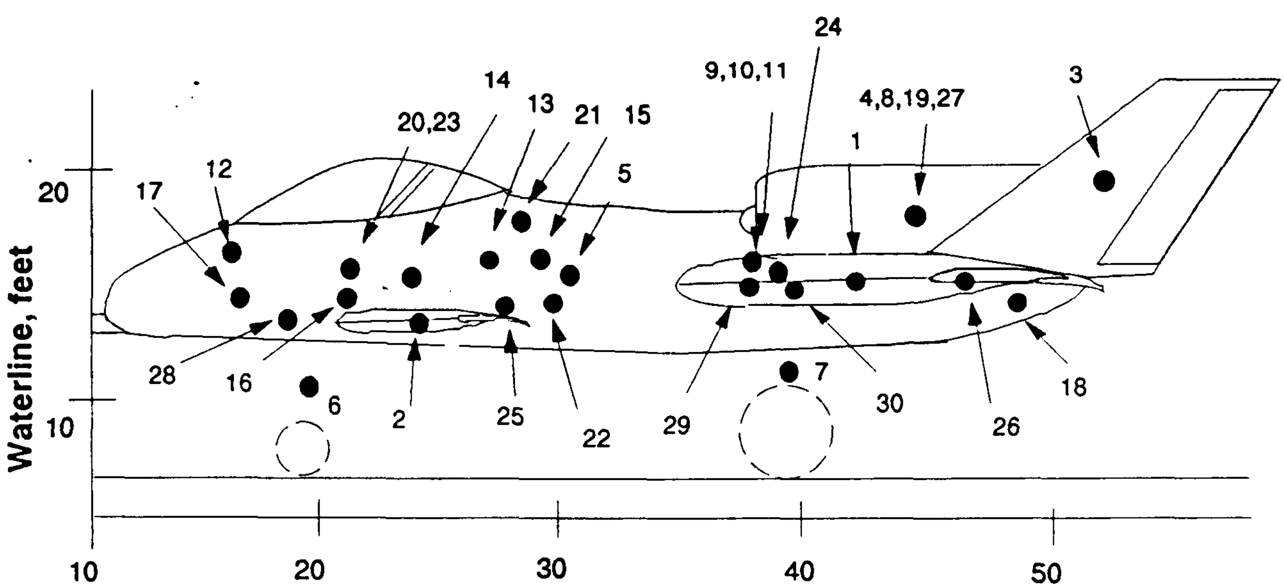


Figure 12.1 Component C.G.Locations

Figure 12.2

12.2 Moments of Inertia

The moments of inertia were calculated using fundamental equations. The main reason that these section properties lack symmetry is the nose gear and gun had to be placed slightly away from the fuselage centerline. The nose gear was placed at away from the centerline to make room for the gun and its barrel. The gun is not directly on the centerline, because the fireline of the gun had to be placed there to avoid large yaw moments when the gun is fired.

The following values for moments of inertia for the *Guardian* were obtained:

Ixx =	3507	slug-ft^2
Iyy =	95798	slug-ft^2
Izz =	92429	slug-ft^2
Ixy =	1106	slug-ft^2
Iyz =	239	slug-ft^2
Ixz =	12267	slug-ft^2

13.0.

AERODYNAMICS

13.1. Airfoil Selection

The airfoil section chosen for the *Guardian* is a modified supercritical airfoil labeled the DSMA-523. A supercritical airfoil section was chosen over a more conventional airfoil as significantly higher drag-divergence Mach numbers and higher maximum lift coefficients are achieved. As shown in the Cl vs. angle plot (Figure 13.1.), a maximum section lift coefficient of 2.0 is reached at an angle of attack of 18 degrees.. This value represents a marked increase over conventional airfoils, which increases the range and flexibility of the wing. The airfoil section is shown in Figure 13.2, and aerodynamic data was obtained from wind-tunnel data taken at the NASA Ames Research Facility.

Figure 13.1 Lift Slope for DSMA 523 Airfoil

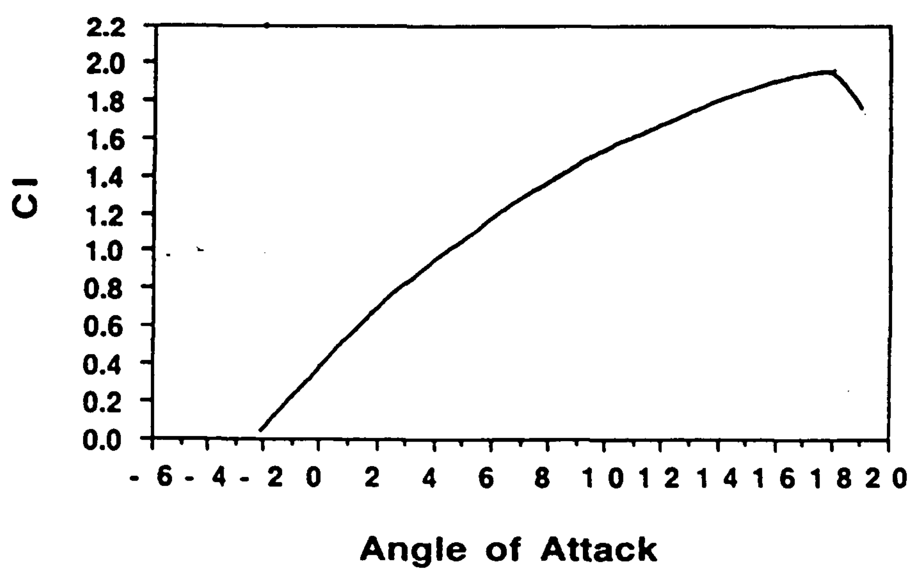
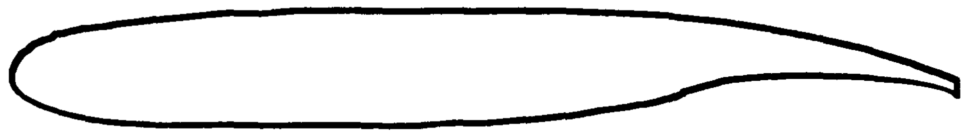
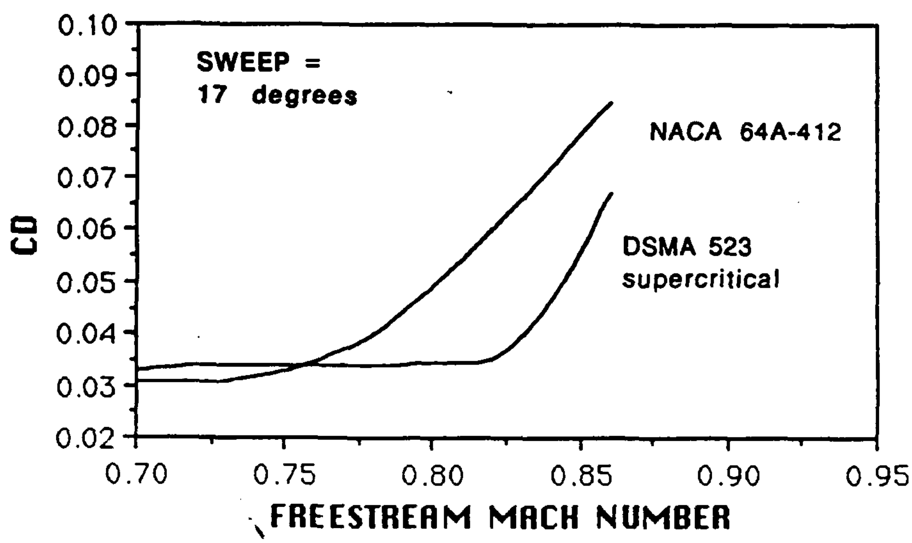


Figure 13.2 DSMA 523 Supercritical Airfoil Section



With an airfoil drag-divergence Mach number of 0.72 at cruise conditions, a wing sweep angle of 17 degrees was found to allow maximum thickness (and therefore lower wing weight), while achieving a total wing drag divergence Mach number of 0.82. As shown in Figure 13.3., the incorporation of a supercritical airfoil on the *Guardian* wing planform increases the Mdd significantly over a conventional NACA 64 series airfoil.

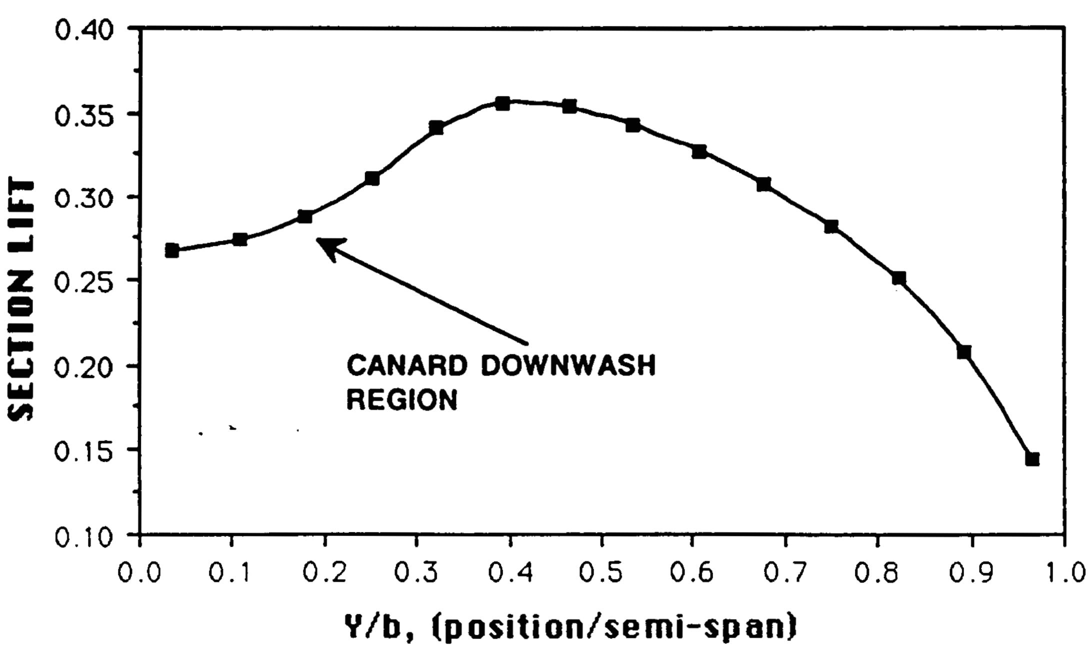
Figure 13.3 Effect of Airfoil on Wing Mdd



13.2. Wing Lift

The *Guardian*'s wing carries a non-elliptical lift distribution which is highly affected by the upstream canard. Figure 13.4 shows a typical distribution at cruise conditions, and the downwashed inboard section is quite visible. This figure shows the lift produced along the span normalized by the MAC, and assumes a canard trim angle of -0.5 degrees for longitudinal trim. This distribution is difficult to analyze using standard theoretical equations due to its unusual shape, and therefore wing lift was determined by numerical integration of the section lift over the span. These distributions were obtained by use of a vortex-lattice computer code capable of determining multi-element interaction. The determined wing lift slope is 4.87 per degree and is shown in Figure 13.5.

Figure 13.4 Wing Spanwise Lift at Cruise



The stall characteristics are of particular interest when a canard configuration is used, as maximum Cl values shift along the semi-span,

and stalling on the outboard sections can occur. As will be discussed in Section 13.5, the canard placement is designed to achieve canard stall prior to wing stall as well as maximum lift at low speed flight, with 20 degree flap deflection. For this reason, at high speeds, the necessary trim angle of the canard does not provide canard stall prior to wing stall. The wing stall angle is also shown in Figure 13.5, and the position of initial stall can be seen in Figure 13.6. This Figure shows the local lift coefficient along the wing span, with stall occurring at 17 degrees angle of attack (Clmax(local) = 2.0). In order to avoid wing stall from occurring at high speed (no flap/slat extension), a stall warning system or avoidance control system must still be implemented.

Figure 13.5 Wing Lift Coefficient vs Angle of Attack

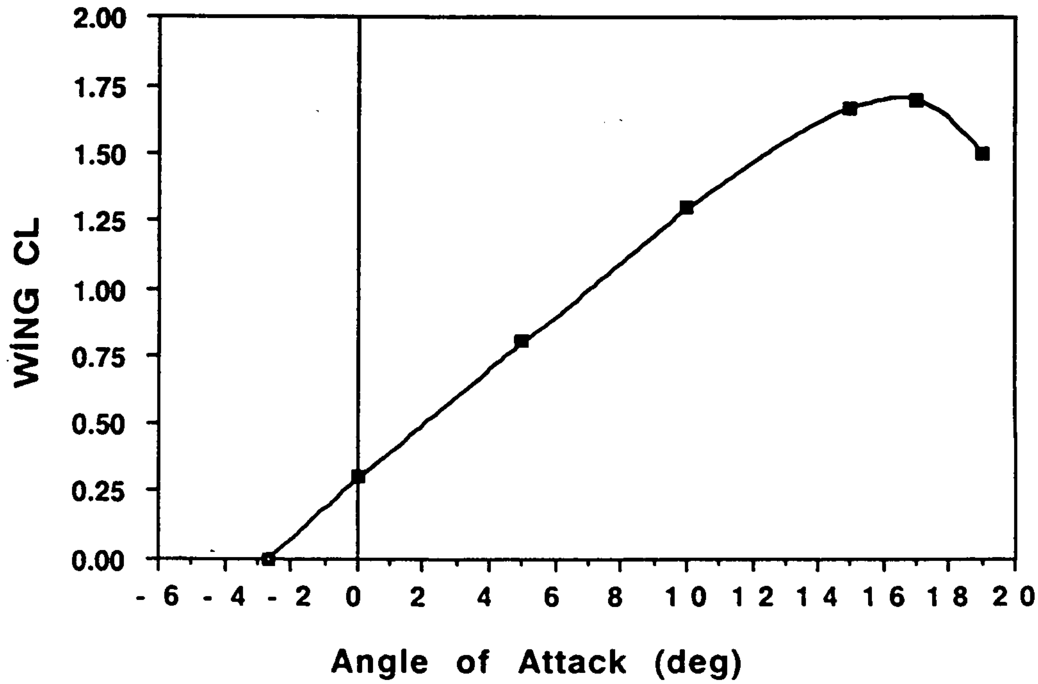
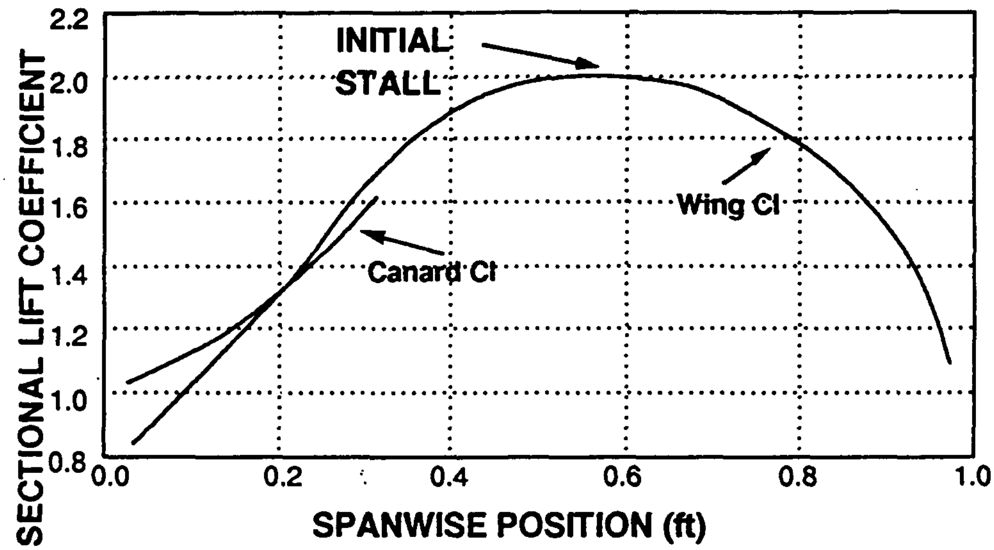


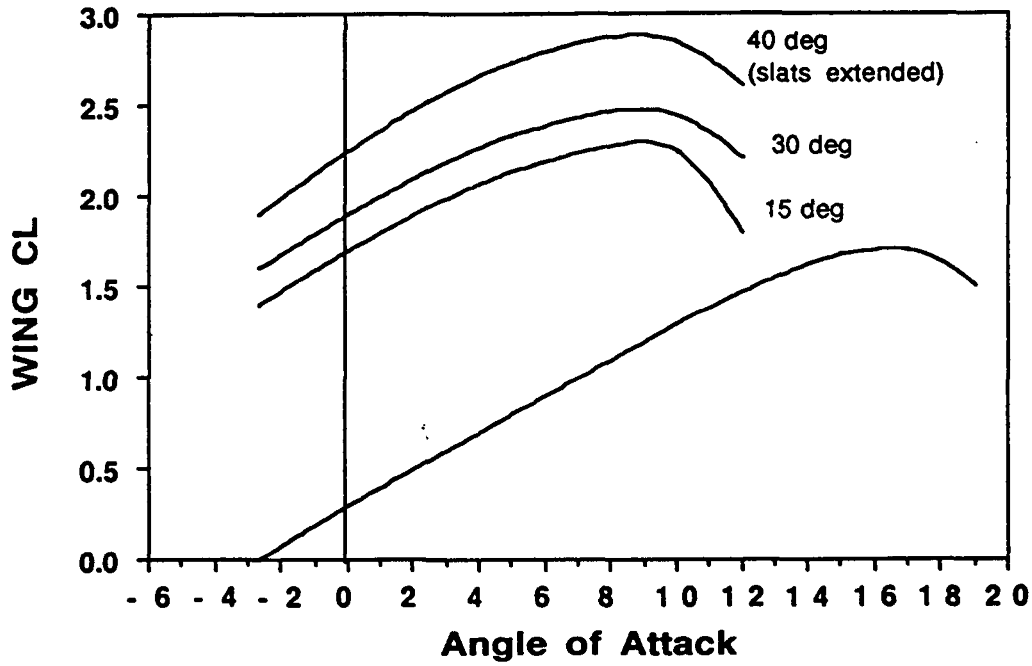
Figure 13.6 Sectional Lift Distribution at Stall



13.3. High-Lift Devices

The need for high lift coefficients during takeoff and landing to achieve the 2000 ft airstrip requirements made it necessary add full span flaps as well as leading edge slats. The use of fowler flaps, though more expensive than plain flaps, were necessary in order to achieve the excellent takeoff distances required. The effect of these devices is to increase the wing maximum lift coefficient to as high as 2.54 with 40 degrees of flap and full slat extension. Figure 13.7 shows the effect on wing lift slope of the high-lift devices, assuming fixed canard incidence angle. The maximum lift coefficient increases to as high as 2.74 with 40 degrees of flap deflection and slats fully extended, with the contribution of the slats being to increase the change in maximum CL from 0.83 to 0.94. Takeoff calculations assume a 30 degree flap deflection with no slats, while landing assumes 40 degrees of flaps and full slat extension. The use of canard incidence to increase this value further is discussed in Section 13.5.

Figure 13.7 Effect of High-lift Devices on CLmax



13.4 Canard Sizing and Placement

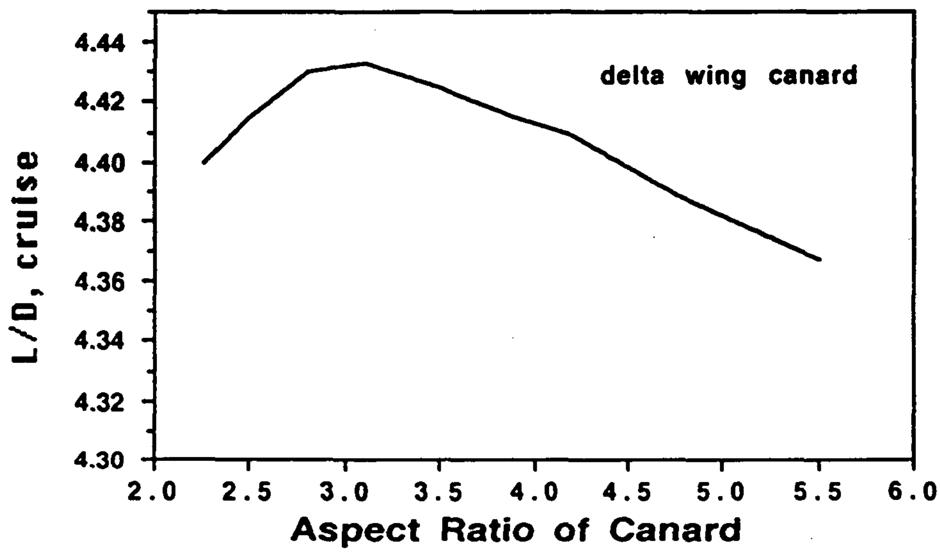
The *Guardian*' s canard location and size were chosen to optimize wing / canard interference effects, while limiting interference with the airflow entering the engine inlets. As the canard is the primary longitudinal control surface, a size of 56 ft^2 was required to allow maximum maneuvering capability, while remaining small enough to keep the aircraft longitudinally stable over the flight regime.

The canard-low configuration tends to reduce downwash effects on the wing over a linear canard/wing arrangement, while sensitivity studies have shown that aerodynamic performance is similar to a more typical canard-high configuration. Because the canard surface must create lift during cruise to achieve longitudinal trim (see Section 14.0), it tends to downwash the main wing over the inboard section. A plot of spanwise lift

distribution over the main wing is shown in Figure 13.4. The downwash effect of the canard is clearly visible, and the lift distribution is seen to shift out toward the wing tips. This imposes larger moments on the wing structure than would appear in tail aft configurations, while causing stall further along the wing span.

Canard aspect ratio was at first quite high in order to avoid wingtip vortices from interfering with engine inlets, but lower aspect ratios were found to increase the overall L/D at cruise conditions by improving wing lift distribution, and were therefore chosen (see Figure 13.8.).

Figure 13.8 Effect of Canard AR on Aircraft L/D

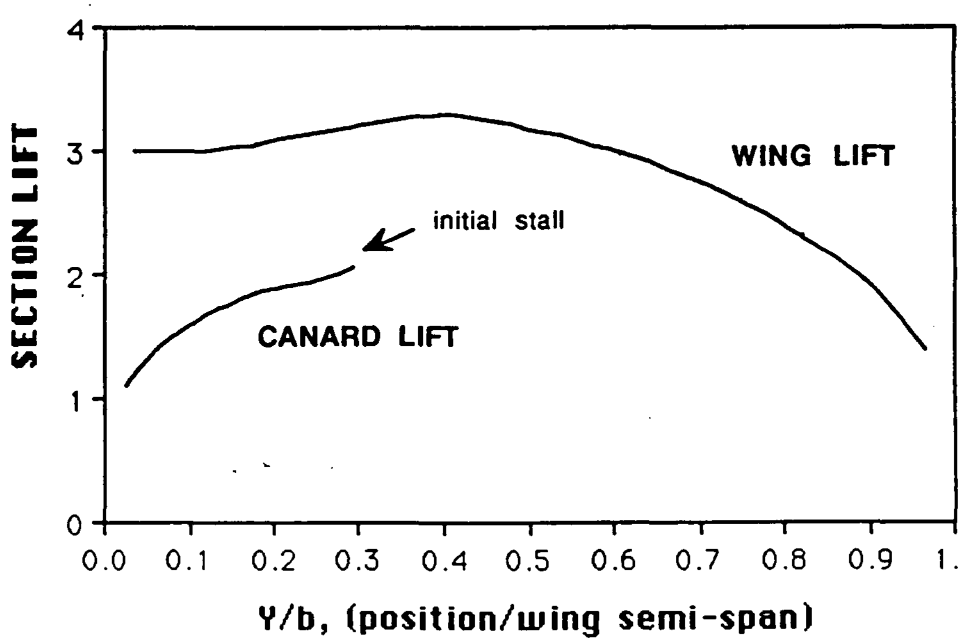


The delta-wing configuration of the canard was chosen, as it tends to cause vortices to build up along the leading edge and to shed outward at the wing tips (away from the engines). Implementing these two design parameters on the final aircraft allows maximized L/D characteristics, while eliminating engine inlet problems over normal flight conditions.

13.5 Canard Incidence

The entire canard surface is capable of rotating in order to produce longitudinal pitching moments, as well as to influence airflow over the main wing. In order to maximize total aircraft lift at low speeds (i.e. takeoff and landing), the canard was positioned in order to achieve a flat lift distribution over the main wing at low speed trim. The position selected is 1.7 wing chords in front of, and 0.2 chords below the main wing. Figure 13.9. shows the canard and wing spanwise lift distributions at low-speed trim conditions (at 119 knots), and an angle of attack of 17 degrees. The flattened lift distribution if the main wing is apparent, and this is

Figure 13.9 Lift Distribution at Low Speed Trim



beneficial, as it postpones stall on the inboard stations, and allows overall maximum lift from the wing to increase. Also, the maximum

canard section lift coefficient reaches stall condition before any point on the wing, which causes canard stall (in case of sudden wind gusts or pilot error), and avoids main wing stall. The canard incidence angle at this condition is -3.4 degrees, which can be automatically set by the on-board flight control computer. At higher speeds, this maximized lift and canard stall must be sacrificed in order to achieve trim conditions, but this is not as vital as flight near stall conditions is not often necessary at high speeds. The section maximum lift coefficients of the canard and wing are 1.7 and 2.74, respectively, and the effects on wing lift and pitching moments due to full flap and slat extension are accounted for.

13.6 Drag Predictions

13.6.1 Wetted Areas

During high subsonic flight speed, the skin friction drag becomes the dominant part of the total drag on an aircraft. The major cause of skin friction drag is the wetted area of an aircraft. Since the *Guardian* will be cruising at these high subsonic, the design was chosen to minimize this wetted area whenever possible. The following is a list of the major components and their wetted areas.

Wing	950 sq. ft.
Fuselage	588 sq. ft.
Canards	112 sq. ft.
Vertical Tails	225 sq. ft.
Nacelles	194 sq. ft.

13.6.2 Drag Polars

The total drag of the *Guardian* was determined by calculating the profile and induced drag of each component based on wetted areas and Mach number. The profile drag for each component was determined by finding the flat-plate skin friction coefficient at each Reynold's number. These values were estimated assuming a fully turbulent boundary layer and using the Prandtl/Schlichting approximation. A plot of profile drag, CDo, is provided (see Figure 13.10) which shows clearly the sudden increase in drag at M = 0.82.

Figure 13.10 Profile Drag vs Mach Number

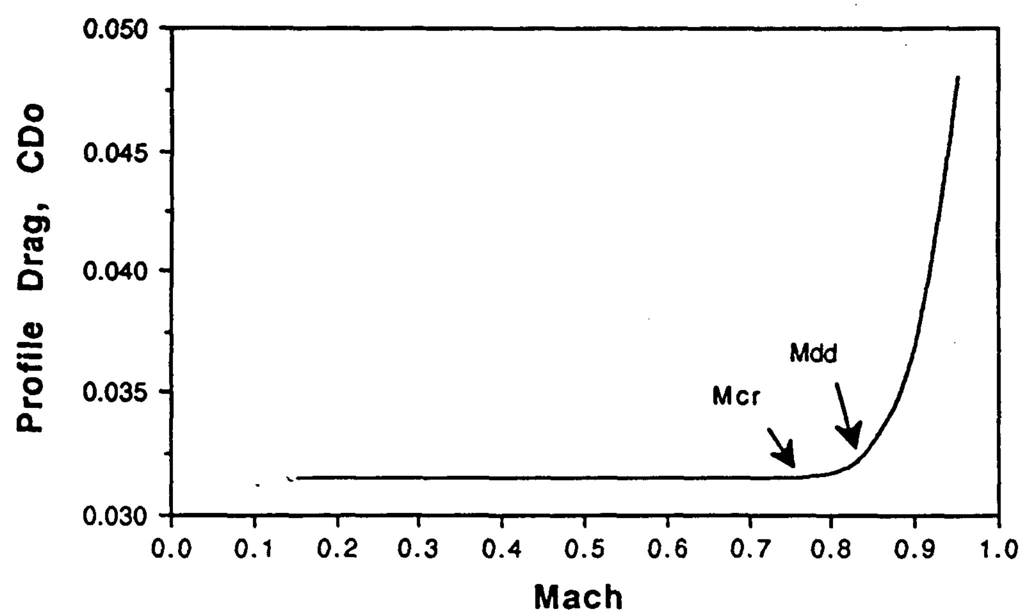
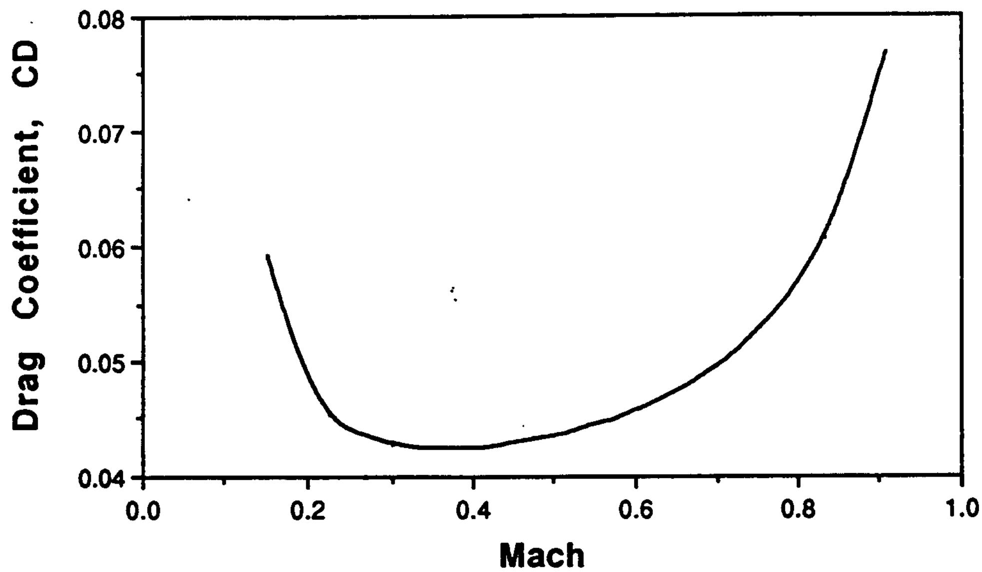


Figure 13.11 shows the change in overall CD of a clean configuration of the *Guardian* as Mach number increases, and the minimum total drag coefficient can be seen at a Mach number of 0.38. At lower Mach numbers,

the large lift coefficients required cause large induced drags, while at higher Mach numbers, profile drag begins to increase rapidly.

Figure 13.11 Drag vs Mach Number



Figures 13.12-13.15 display drag polars based on different flight conditions. Figure 13.12 shows the drag for a clean aircraft with no external payload and gear up (cruising condition). When stores are added to the aircraft, the drag polar shifts very slightly to the right and increases more at higher Mach numbers. Figure 13.13 shows this increase in total drag graphically. This drag is due to the increased skin friction drag over the bomb surface areas and a component of drag due to interference between the wing and bombs. Figure 13.14 demonstrates a drag polar for landing conditions, flaps extended and gear down (landing conditions). Under this condition, the drag increases by more a factor of 10 compared to the drag at cruise conditions, with this increase being primarily due to the flaps. At take-off conditions, partial flaps and landing gear extended and with external stores (takeoff conditions), the

Figure 13.12
Drag Polar for Cruise

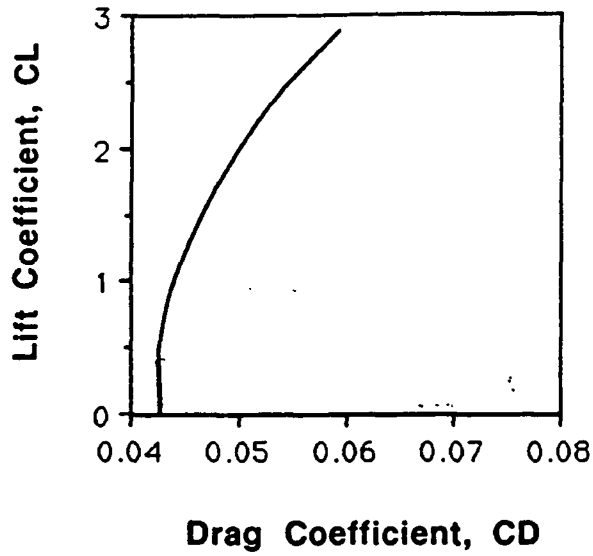


Figure 13.13
Drag Polar for Weapons Load

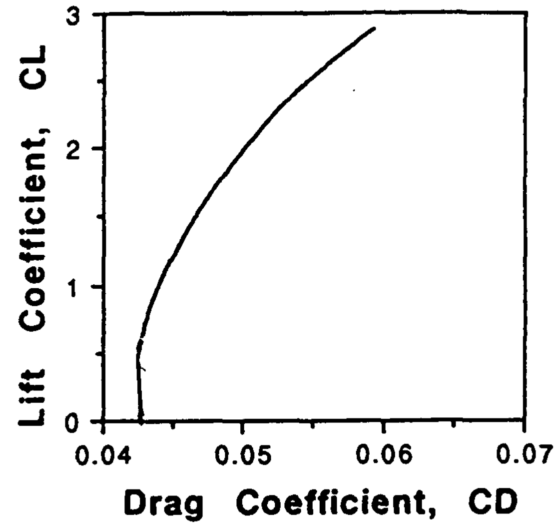


Figure 13.14
Drag Polar for Landing

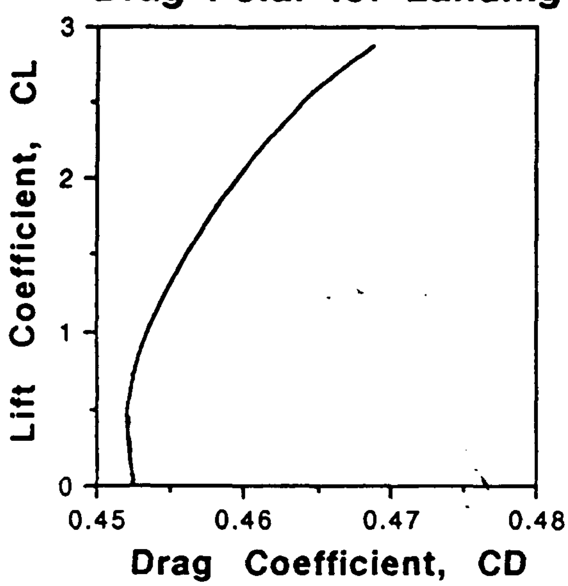
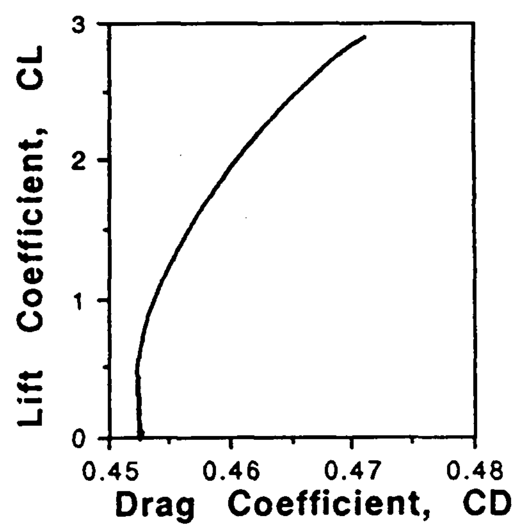


Figure 13.15
Drag Polar for Take-off

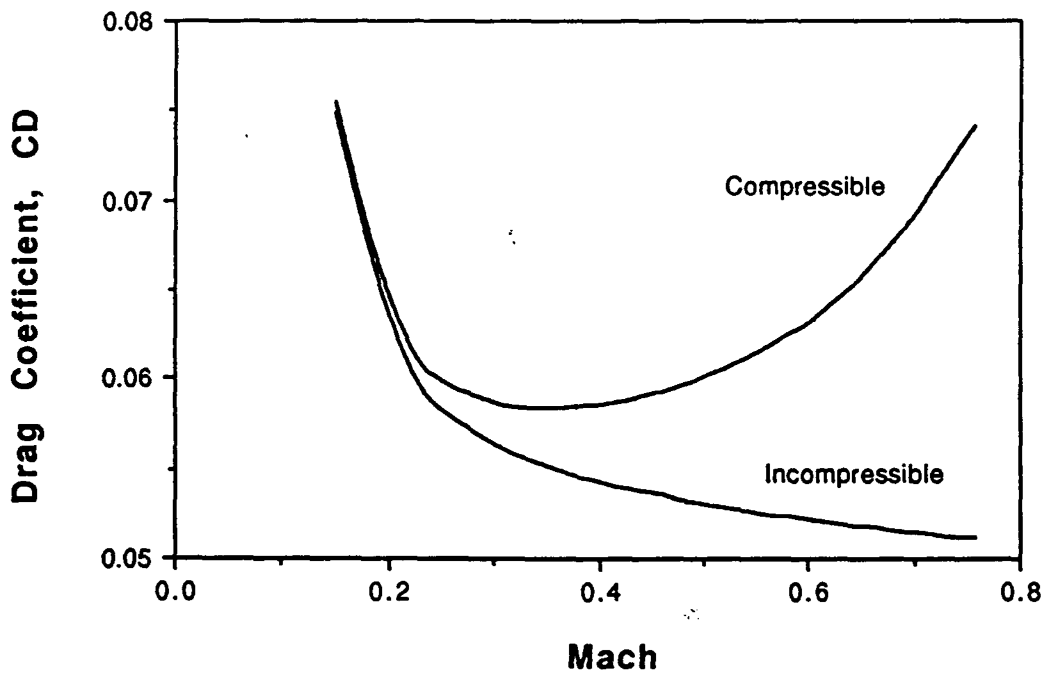


drag increases to a point slightly higher than that at landing. Although the smaller flap deflection required reduces wing drag, the increased drag due to bombs increases overall drag slightly (See Figure 13.15).

13.6.3 Compressibility Effects

In order to account for compressibility of the flow, the Karmen-Tsien Rule for compressibility correction was used to estimate actual drag at each Mach number. Figure 13.16 shows the estimated drag curve over a range of Mach numbers corrected for compressible flow as well as the drag assuming incompressible flow. This figure represents the *Guardian* with full design weapons load during cruise. The increased drag can be seen clearly and, as expected, the assumption of incompressible flow in this Mach region is invalid. As expected, the incompressible flow assumption is invalid after about Mach 0.3. This method was used instead of Laitone's rule or the Prandtl-Glauert, as this method is quite accurate, while being relatively simple to use.

Figure 13.16 Effects of Compressibility on Drag



14.0

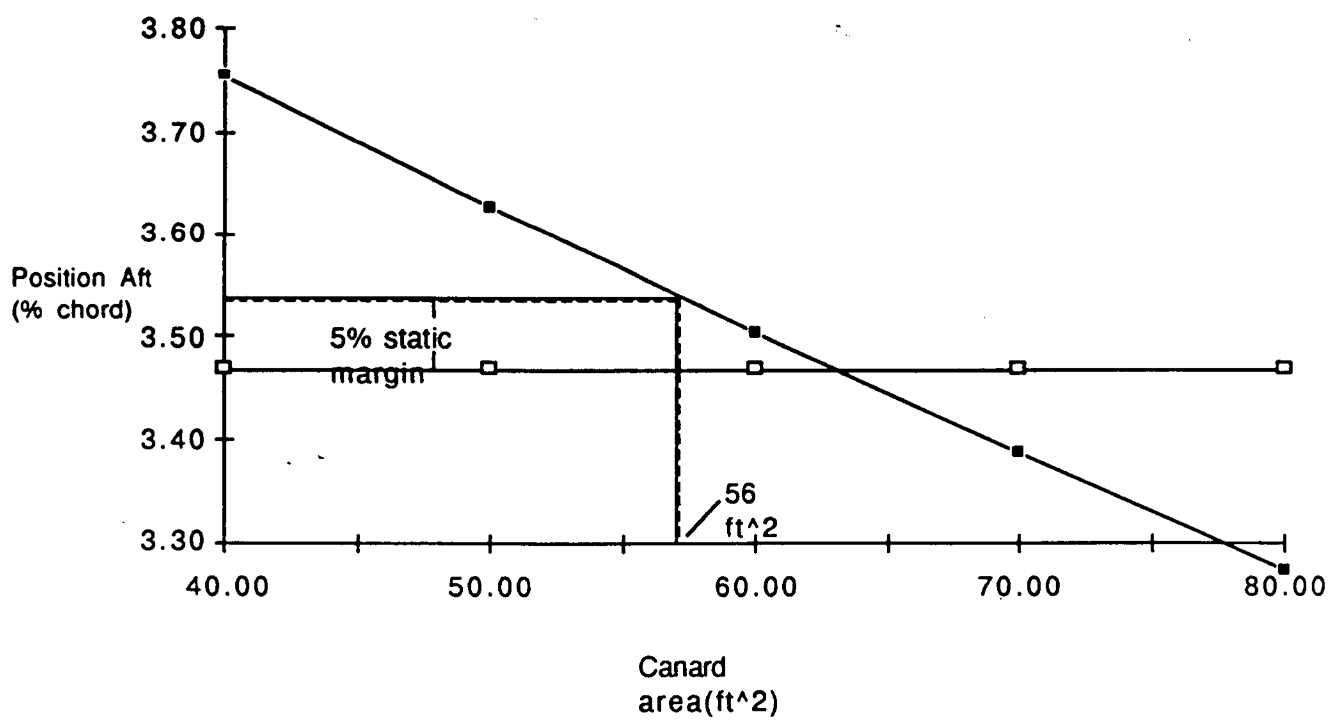
STABILITY AND CONTROL

14.1 Static Stability

The static stability of an aircraft is its tendency to return to its equilibrium condition after a disturbance. The *Guardian* has been design to be staticly stable; specifically a longitudinal static margin of 5% MAC. This static margin was obtained by specific sizing and positioning of the canard. Figure 14.1 show the longitudinal X-plot. A static margin of 5% requires a canard area of 56 ft^2.

Figure 14.1

Longitudinal X-Plot for the Guardian



14.2 Dynamic Stability

The ultimate goal of a stability and control design is that aircraft "feel" good to the pilot. The first criterium is that the aircraft is controllable. Performance means nothing at all if the pilot can't control the airplane. The second criterium is the pilot's opinion of the aircraft. This depends on many factors: how much stick force there is, how easily the plane falls off the intended flight path, how much the pilot must correct for error, and how comfortable the ride is.

The criteria for an aircraft's flying qualities depends on the specific aircraft and the flight phase. These classification's can be found fron Reference 3. The *Guardian* is a Class IV airplane. Class IV represents all high maneuverability airplanes.

The flying qualities of an aircraft are measured by what level they can be classified in. A level 1 fight quality will meet all mission requirements satisfactorily. A level 2 flight quality is adequate, but not considered ideal fron the pilot's perspective. A level 3 flight quality means that the mission can be performed, but the there is excessive pilot workload.

14.2.1 Stability Derivatives

The stability derivative coefficients were appoximated using standard equations. All of the necessary coefficients were found, and then a literal factors analysis was done to determine the flying qualities of the *Guardian*. A discussion of the different motions follows a summary of the stability derivatives.

Table 14.1 is a list of the stability derivative coefficients of the *Guardian*. They have been divided up into three sections: the longitudinal, the lateral, and the control derivatives.

Table 14.1

Summary of Stability Derivative Coefficients

Longitudinal Derivatives

CLu	(sec/ft)	0.064
CMu	(sec/ft)	0.0
CDu	(sec/ft)	0.0
CLa	(1/rad)	5.184
CMa	(1/rad)	-0.356
CDa	(1/rad)	0.772
CLadot	(sec/rad)	-0.069
CMadot	(sec/rad)	-0.058
CDadot	(sec/rad)	0.0
CLq	(sec/rad)	11.715
CMq	(sec/rad)	-9.195
CDq	(sec/rad)	0.0

Lateral derivatives

Clb	(1/rad)	-0.121
Cnb	(1/rad)	0.247
Cyb	(1/rad)	-0.637
Clbdot	(sec/rad)	0.002
Cnbdot	(sec/rad)	0.006
Cybdot	(sec/rad)	0.026
Clr	(sec/rad)	0.067
Cnr	(sec/rad)	-0.455
Cyr	(sec/rad)	0.331
Clp	(sec/rad)	-0.394
Cnp	(sec/rad)	0.012
Cyp	(sec/rad)	-0.092

Control Derivatives

CLic	(1/rad)	0.384
CMic	(1/rad)	0.346
CDic	(1/rad)	0.029
Clds	(sec/rad)	0.025
Cnds	(sec/rad)	0.012
Cydr	(sec/rad)	0.254
Cldr	(sec/rad)	0.020
Cndr	(sec/rad)	-0.071

14.2.2 Literal Factors Analysis

In order to make a preliminary analysis of the *Guardian's* motion's of flight, a few general assumptions had to be made. First, we assumed the aircraft to be rigid. Without this assumption, analysis of aircraft's response would be too difficult and not beneficial at this point in the design. Second, we assumed that the aircraft's deviations from steady state are small. Finally, we assumed that the lateral and longitudinal equations of motion are not coupled to each other. As long as the aircraft's motions are not large amplitute or rapid maneuvers, these assumptions are reasonable. These are all very common assumptions for a literal factors analysis.

A summary of the literal factors analysis is shown on Table 14.2. The quantities shown were the ones used to determine the flight quality level.

Table 14.2
Literal Factors Summary

	Short Period	Phugoid	Dutch Roll	Lateral Roll	Spiral
frequency(rad /sec)	4.65	0.063	7.77	N/A	N/A
Damping Ratio	0.497	0.128	0.227	N/A	N/A
Time Constant	N/A	N/A	N/A	0.018	N/A
Time to Double Amplitude(sec)	N/A	N/A	N/A	N/A	-0.302
Level	1	1	1	1	1

N/A (Not Applicable)

14.2.3 Longitudinal Motions of Flight

The two common dynamic instabilities of interest are the short period motion and the long period, or phugoid, motion. Both are oscillatory. The phugoid motion has a period of 30 seconds or longer. The motion can be described by large changes in amplitude, and the oscillations are very lightly damped. This type of motion must be very seriously considered for any type of transport or cruise plane, where a pilot may leave the controls for a long period of time. But in the case of a fighter aircraft, including CAS, the pilot constantly keeps his hands on the stick. The pilot will normally correct for it unconsciously because it occurs so slowly. The literal factors analysis of the *Guardian* shows that the damping ratio well exceeds that required for level 1 flying quality. The phugoid motion will not present any difficulties to the design.

The short period motion can be described as rapid changes of angle of attack. The short period motion can be a serious problem for pilots of all types of aircraft. If the motion is not stable and too rapid for the pilot to control, the aircraft will very likely depart. The short period frequency for the *Guardian* , determined from the literal factors analysis, was calculated to be 12.3 rad/sec and the damping ratio was 0.154. This is classified as a level one flying quality. This is excellent for a preliminary desgn. As further detail into the *Guardian* is studied, so will these and other handling characteristics. A flight control system will still be useful for aircraft control, and will also allow the stick force to be user-set.

14.2.4 Lateral Motion of Flight

The three lateral modes of motion are the Dutch roll mode, the lateral roll mode, and the spiral mode. The Dutch roll is the only oscillatory mode of the three. It is a combination of back and forth rolling and yawing motions. The Dutch rol mode for the *Guardian* has a frequency of 6.79 rad/sec and a damping ratio of 0.051. This classifies the *Guardian* in a level 2 flying quality for this mode. It will be desirable to have a level 1 flying quality aircraft, therefore the flight control system will be used to raise the damping ratio to a minimum of 0.19.

The lateral roll mode is a single degree of freedom roll. The roll time constant is inversely proportional to the roll damping, Lp. For the case of the*Guardian*, the roll damping is very large, producing a small time constant of 0.022 seconds, far below the maximum allowable roll time constant of 1.0 sec for level 1 flight. The high cruise velocity is a good contributor to the *Guardian*'s excellent roll damping characteristics.

The spiral mode for the *Guardian* has been found to be stable, which solves the problems of directional and spiral divergence. The stable response is due to the large dihdral effect and the yaw damping. The criterium for level 1 spiral is that the aircraft either be stable (as is the *Guardian*) or, if unstable, have a time to double amplitude of 12 seconds minimum.

15.0

AVIONICS

Presented below in Table 15.1 is a list of the main and supporting systems. Other minor systems not in listed Table 15.1 are mentioned and explained in the ensuing sections which discuss the systems listed here.

Main Systems	Support Systems
Flight Controls (HOTAS)	Fuel
Weapons (LANTIRN)	Air Conditioning
Navigation (LANTIRN)	Environmental Control
Electronic Countermeasures	Electrical
Radar Warning Receiver	Auxiliary Power
Communications	Hydraulic

Table 15.1 *Guardian* Systems

15.1 Flight Control System

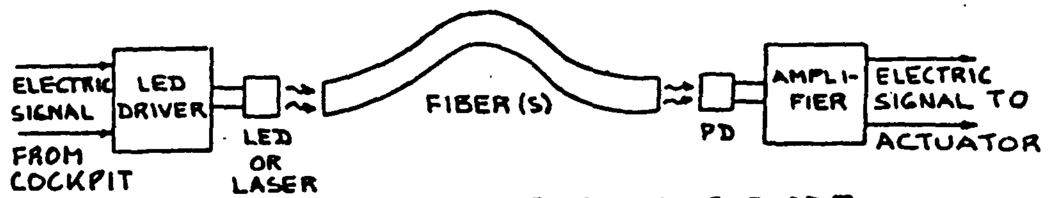
The *Guardian* relies on a triple redundant fly-by-wire flight control system. Fly-by-wire systems have been proven reliable and are already in second generation development. Such systems reduce the pilot's work-load by allowing him to concentrate on engaging weapons against the enemy rather than on aircraft control. Three independent flight control computers (two back-ups) are located far apart from each other in the fuselage. Fly-by-wire systems also weigh less than standard, previously used mechanical flight control systems. Electrohydrostatic actuators are

used for all control surfaces because they also reduce the weight and cost of the control system by eliminating a voluminous hydraulic system. Electrohydrostatic actuators each have their own hydraulic reservoirs, eliminating the threat of any main hydraulic lines being damaged, resulting in total loss of control. They also provide easy maintenance and repair and are compatible with next generation optical flight control systems. An illustration of a linear electrohydrostatic actuator is presented in Figure 15.1. Table 15.2 lists the redundancy of certain actuator locations.

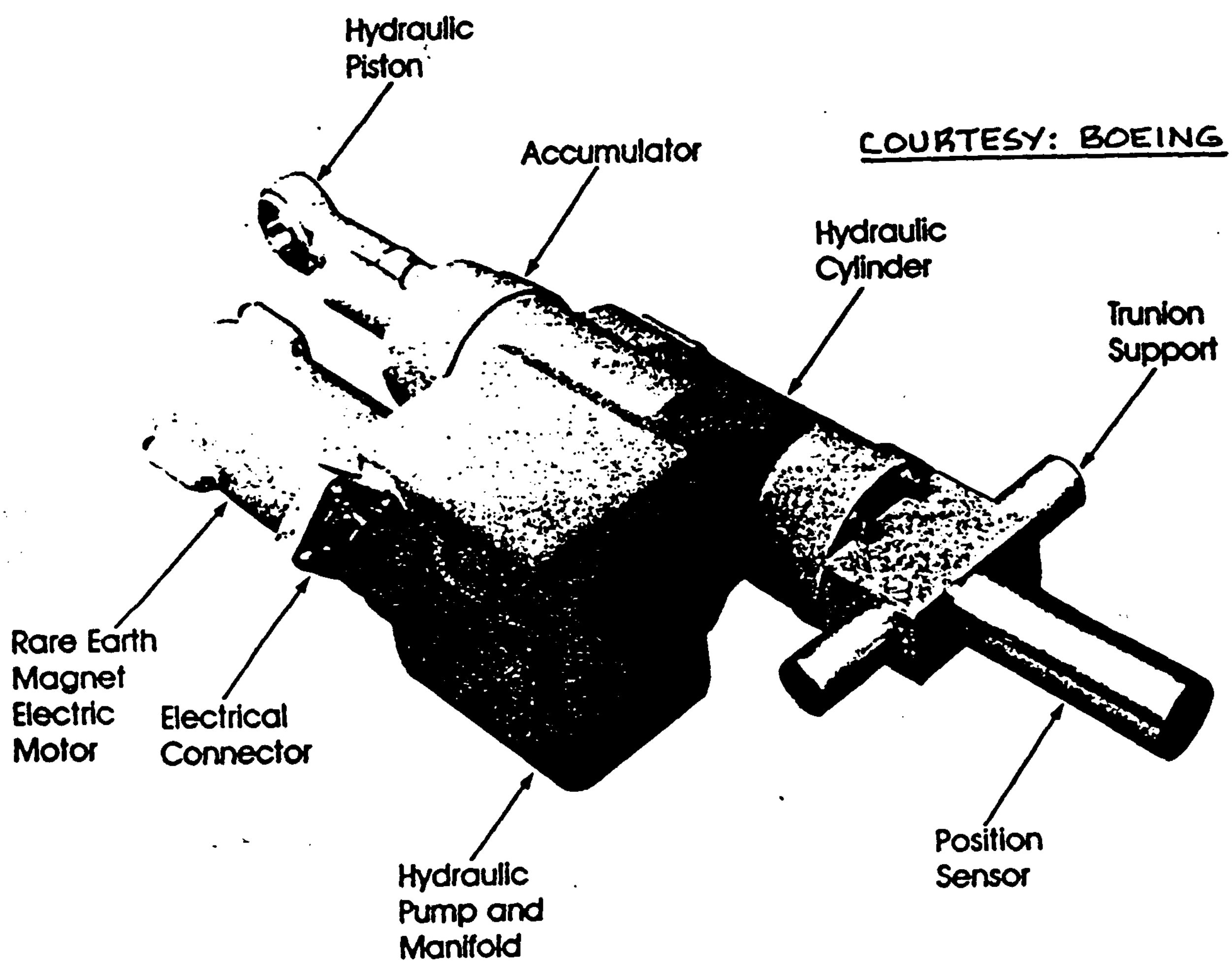
Control Surface	Actuator Type	Actuators/Surface
Canards	Linear	2
Flaps	Rotary	2
Leading Edge Slat	Rotary	1
Rudders	Linear	2
Spoilers	Rotary	1

Table 15.2 Electrohydrostatic Actuator Breakdown

The canards and rudders are operated via linear electrohydrostatic actuators because they can respond quickly with large control surface deflections. All other control surfaces are equipped with rotary electrohydrostatic actuators. All flight control surfaces are interfaced with the main flight control computer which is directly linked to the HOTAS (Hands On Throttle And Stick) computer system. The flight control and HOTAS computers can be programmed to avoid lethal maneuvers and monitor flight control responses. Also tied into the flight control



Optical Signalling of the Actuator



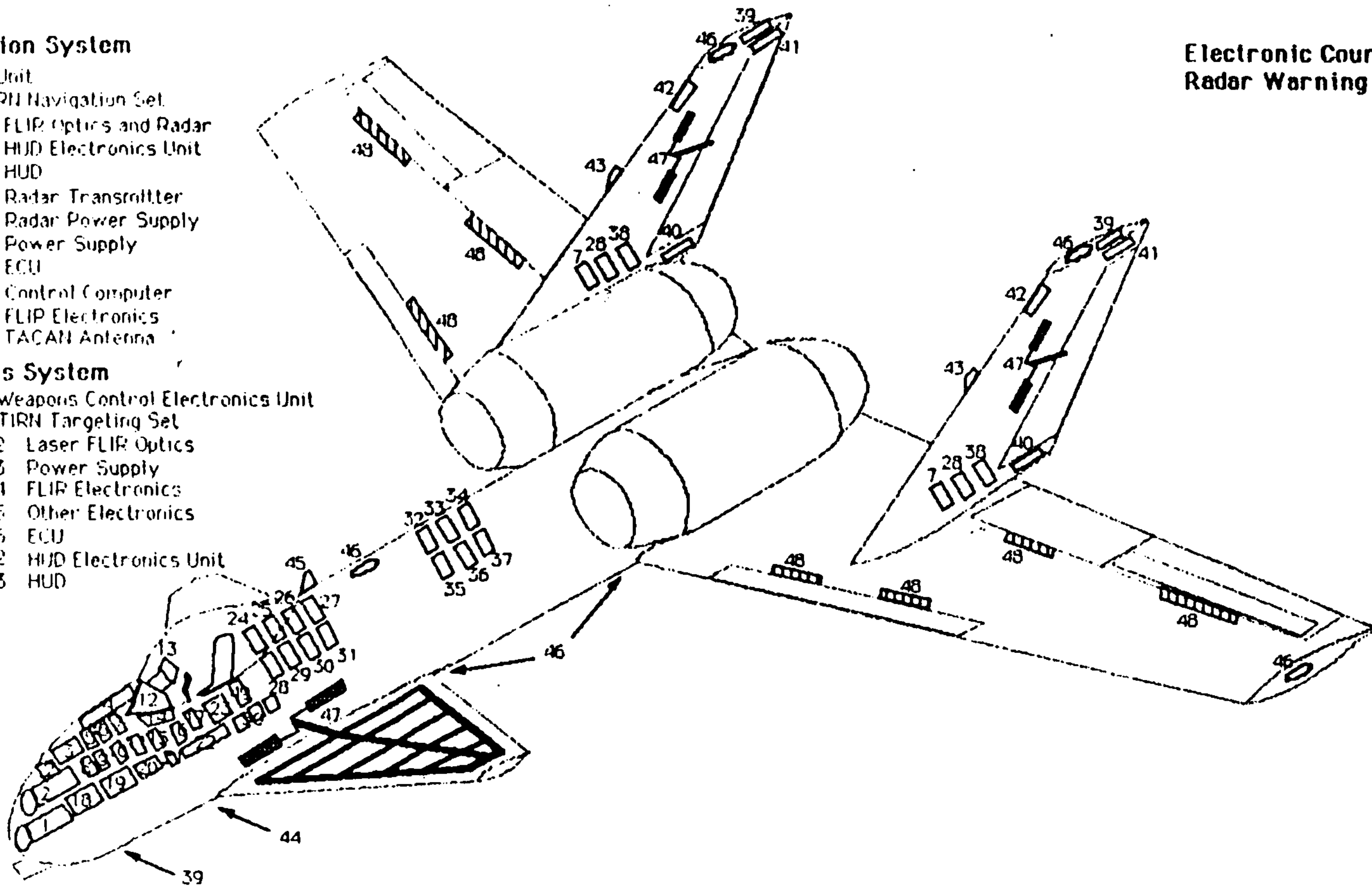
Example Electrohydrostatic Actuator

Figure 15.1

computer are multi-function flight condition indicators. The locations of flight control system components are shown in Figure 15.2.

15.2 Weapons System

Precision delivery of ordnance is achieved with the on-board LANTIRN (Low Altitude Navigation and Targeting Infrared system for Night) system which interfaces with the weapons control computer. The LANTIRN system is currently in use with a HUD interface and was proven very effective and reliable in combat in the Desert Storm operation of 1991. However, the decision to permanently install the LANTIRN system was driven by the fact that the LANTIRN targeting system is capable of delivering ordnance with a circular error probability of no more than two feet (Ref 4). LANTIRN targeting system component locations are illustrated in Figure 15.2. Because the LANTIRN targeting system uses Forward Looking InfraRed (FLIR) data acquisition rather than radar, it is extremely difficult for the enemy to detect it during operation. The LANTIRN targeting system provides night and all weather capability and can be interfaced with the LANTIRN navigation system providing two fields of view for enhanced target recognition and acquisition. The inertial navigation system cues the targeting system line of sight. The LANTIRN targeting system interfaces with the *Guardian*'s HUD and fire control systems providing laser designation and ranging information from its Laser RangeFinder/Designator (LRF/D) enabling the precise delivery of ordnance. The LANTIRN targeting system includes its own Environmental Control Unit (ECU), an essential component for ensuring the reliability of



Navigation System

- 9 INS Unit
- LANTIRN Navigation Set
  - 1 FLIR Optics and Radar
  - 12 HUD Electronics Unit
  - 13 HUD
  - 18 Radar Transmitter
  - 19 Radar Power Supply
  - 20 Power Supply
  - 21 ECU
  - 22 Control Computer
  - 23 FLIP Electronics
  - 45 TACAN Antenna

Weapons System

- 11 Weapons Control Electronics Unit
- LANTIRN Targeting Set
  - 2 Laser FLIR Optics
  - 3 Power Supply
  - 4 FLIR Electronics
  - 5 Other Electronics
  - 6 ECU
  - 12 HUD Electronics Unit
  - 13 HUD

Electronic Countermeasures (ECM) and Radar Warning Receiver (RWR) Systems

- 7 DF Reciever
- 17 ECM Control Computer
- 24 Forward Repeater
- 25 C/D Reciever
- 26 Analysis Processor
- 27 Techniques Generator
- 28 Power Amplifier
- 29 ECU
- 32 S/H Reciever
- 33 S/H Controller
- 38 Aft Repeater
- 39 DF Antenna
- 40 Aft Jamming Antenna
- 41 Radar Warning Receiver
- 42 VHF Antenna
- 43 IFF/UHF Antenna
- 44 C/D Antenna

Communications System

- 10 IFF Unit
- 35 Communications System Control Unit
- 42 VHF Antenna
- 43 IFF/UHF Antenna

Flight Control System

- 15 Flight Control Computer
- 31 Back-up Flight Control Computer #1
- 34 Back-up Flight Control Computer #2
- 47 Linear Electrohydrostatic Actuators
- 48 Rotary Electrohydrostatic Actuators
- 49 HOTAS Interface Control Computer

General Avionics Components

- 8 Video Recorder
- 14 Multi-purpose Display
- 30 Air Conditioning and Environmental Control Systems Control Computer
- 36, 37 Additional Electronics Slots

Figure 15.2 Avionics Systems Layout

the electronics. Finally, the LANTIRN system contains several Line Replaceable Units (LRUs), for ease of maintenance and repair.

15.3 Navigation System

The counterpart to the LANTIRN targeting system is the LANTIRN navigation system, the *Guardian*'s primary navigation system. Using a wide field of view FLIR and a terrain following radar, the LANTIRN navigation system provides the pilot with a HUD night window for low level flight and en route adverse weather penetration. The HUD is, therefore, an essential part of the navigation system. The *Guardian* uses the GEC Avionics F-16 LANTIRN HUD sight. This HUD is LANTIRN dedicated with a generous field of view of thirty degrees in the azimuth by eighteen degrees in the vertical.

Other important instruments in the navigation system include the Inertial Navigation System (INS) for long range navigation and TACtical Air Navigation system (TACAN) for backup. See Figure 15.2 for an illustrated description of the locations of navigation system components. Note that the FLIR and Laser Range Finder components of the LANTIRN system require a transparent "window" in the nose of the *Guardian* because they use non-material penetrating wavelengths of light. This "window" would be fashioned after the one on the Lockheed F-117A. Finally, although LANTIRN is more expensive than TACAN and INS systems, it is expected to become the standard of the *Guardian's* generation of aircraft and its superiority over other systems warrants the cost.

15.4 Electronic CounterMeasures and Radar Warning Receiver Systems

The *Guardian* uses the Loral Electronic Systems AN/ALQ-178 ECM System to protect itself from hostile electronic surveillance and alert the pilot when his aircraft has been "locked-on" by an enemy tracking system. The AN/ALQ-178 is an integrated Radar Warning Receiver (RWR) and Electronic Counter Measures (ECM) suite used in the General Dynamics F-16 (Ref 2). The Bush Administration's FY 1990/91 included allocations for 146 General Dynamics F-16 to A-16 conversions to supplement 225 updated Fairchild A-10As (Ref 1). The A-16 is the CAS version of the F-16. This event indicates that the AN/ALQ-178 ECM electronics suite is the best present choice for the *Guardian* since it is intended to replace the current generation U.S. Air Force CAS aircraft, the A-10. However, the features and proven capability of the AN/ALQ-178 ECM System also influenced the Baghdad Express decision to incorporate it in the *Guardian*. The system operates from a central programmable computer with independent microprocessors dedicated to RWR, display and jamming functions (Ref 2). The system can also operate as an independent threat warning system without the jammer sub-system. This configuration reduces the cost of the system, though the system is already cost effective since it has been proven and is in production. AN/ALQ-178 ECM System components are illustrated in Figure 15.2.

15.5 Communications System

The *Guardian* utilizes a standard, and therefore cost effective, communications system including UHF and VHF radio systems. A key element of the communications system is the Identification Friend or Foe (IFF) sub-system which allows immediate and reliable automatic identification of other aircraft. The Teledyne Electronics AIXP Advanced Interrogator/Transponder was chosen for its installation flexibility. Figure 15.2 shows communications components locations.

16.0 SYSTEMS LAYOUT

16.1 Fuel System

The fuel system of the *Guardian* consists of the HOTAS computer control unit and three fuel tanks located in the fuselage each with two dedicated fuel pumps which direct fuel to an engine or can transfer fuel to an adjacent fuel tank if needed. The pumps are operable in any attitude. The fuel system is illustrated in Figure 16.1. The fuel tanks are reticulated foam which are self sealing, prevent explosion and eliminate undesirable slosh. Fire retaining walls enclose the fuel tanks. The fuel tanks can be filled from any of five refuelling ports. Two gravity feed ports are located on the dorsal mid-section of the fuselage. One pressure feed port is located on each wing. Connected to these pressure feed lines are pumps dedicated to external fuel tank hook-ups at several "hard points" on the wings. The fifth refuelling port is just infront of the cockpit providing air-to-air refuelling capability to the *Guardian*. This port can also be used with ground refuelling equipment. A fuel vent line extends out the tail of the fuselage.

16.2 Air Conditioning and Environmental Control Systems

The air conditioning system and environmental control systems consist of two engine driven oxygen generation pumps, environmental

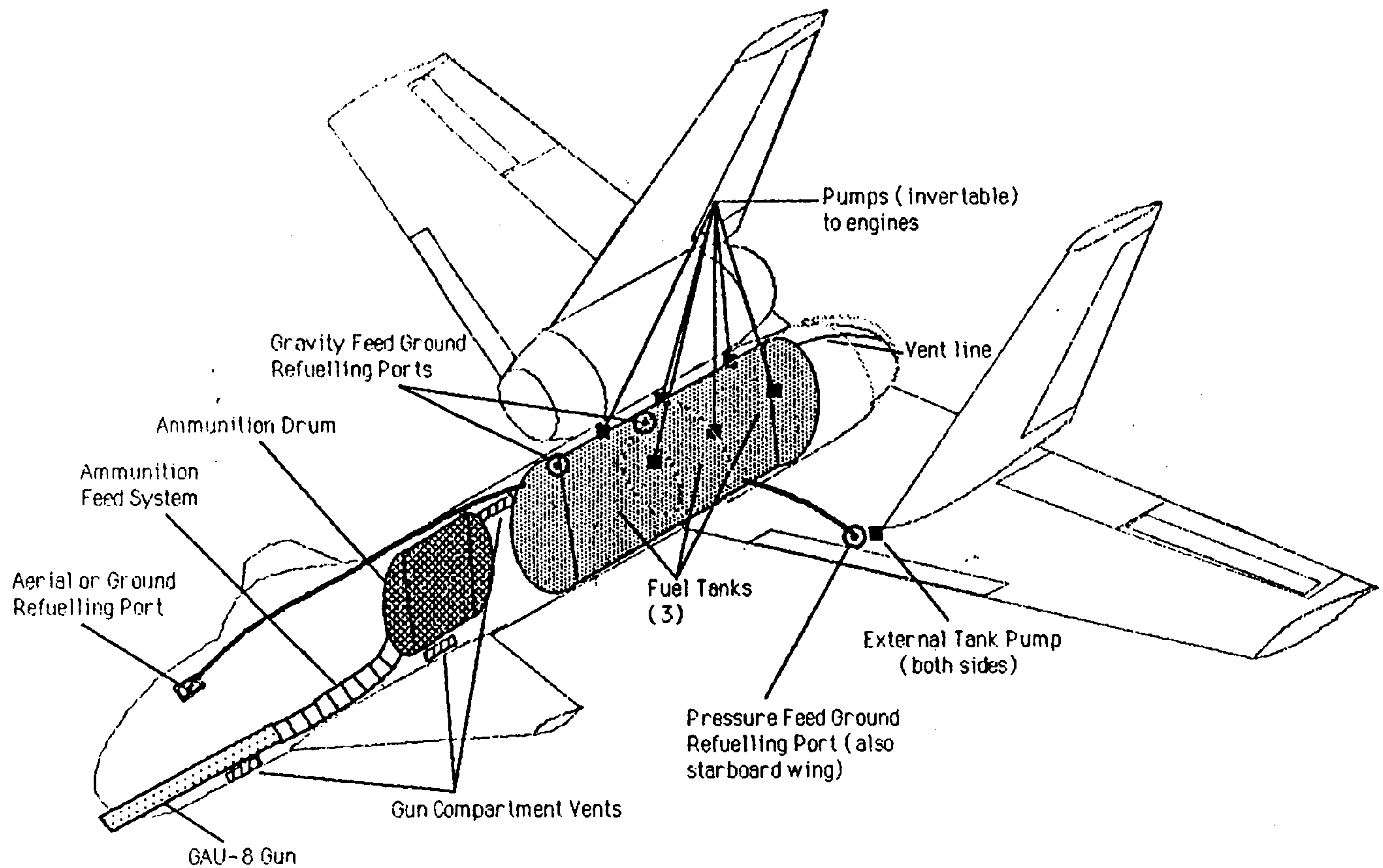


Figure 16.1 Fuel and Cannon Systems Layout

control units (ECU) in various locations and a central control computer which regulates both systems. Figure 16.2 illustrates these systems. The Air Conditioning system functions to regulate the cockpit temperature.

16.3 Electrical System

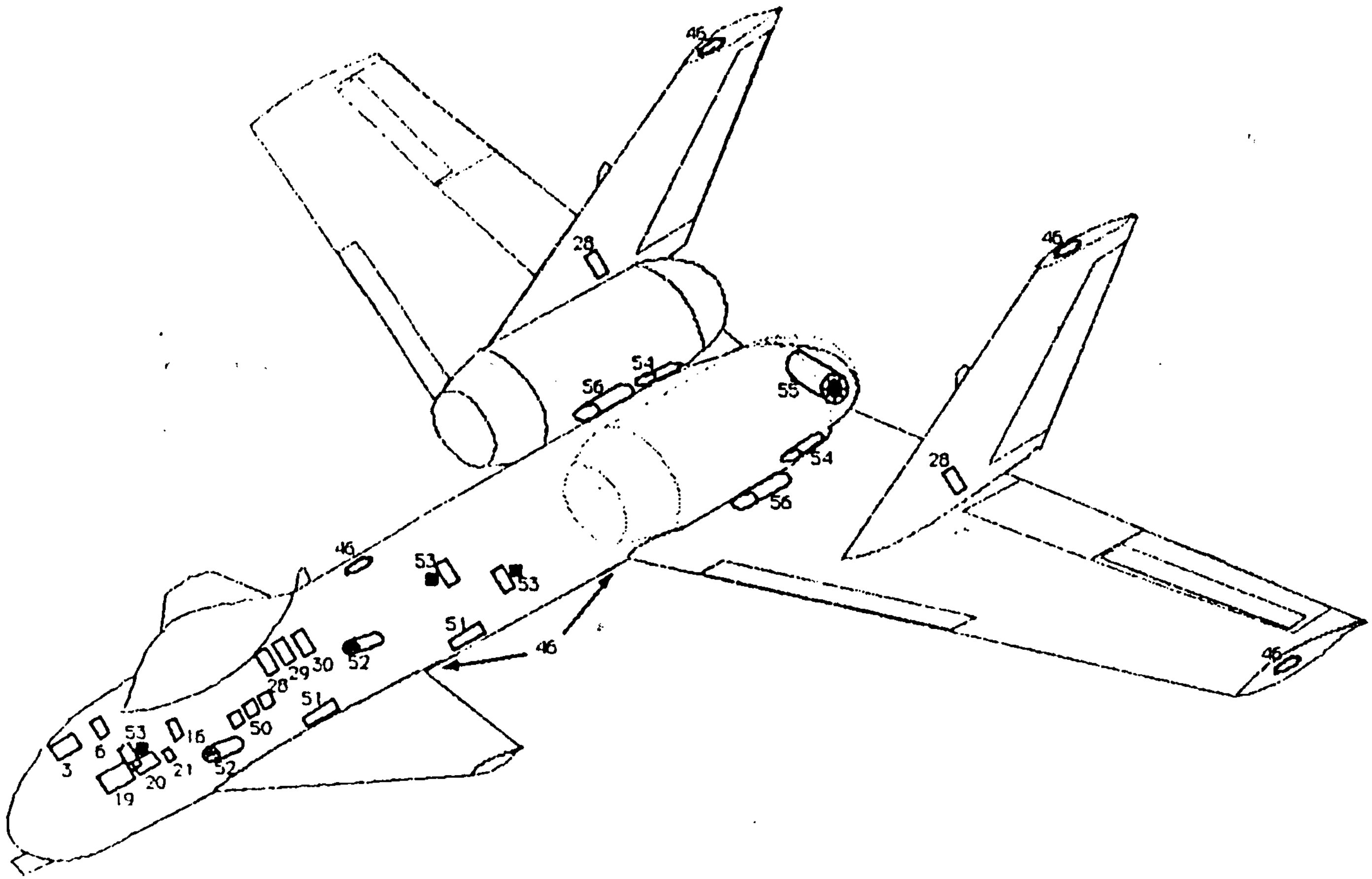
The electrical system consists of two engine driven generators, accumulators and batteries. The generators are the primary power source of power for all avionics and instrumentation systems, the video recorder and light beacons. The batteries provide emergency power for flight computers and essential electronics. All wiring is contained in conduits for safety and easy maintenance.

Component	Power Developed (KVA)
Engine driven generators	90 - 110
Ram air turbines	10 - 20
Batteries	0.5 - 1.0

Table 16 Power Developed by Electrical System Components

16.4 Auxiliary Power System

Located in the tail of the fuselage, the APU can be used to supply power to wing mounted stores and provides back-up power should the generators fail. Complimenting the APU, two ram air turbines (RATs) are located in the forward ventral section of the fuselage to provide



Electrical System

- 3 Power Supply
- 16 Electrical System Control Computer
- 19 Radar Power Supply
- 20 Power Supply
- 28 Power Amplifier
- 46 Light Beacon
- 50 Batteries
- 51 Accumulator

Auxiliary Power and Landing Gear Systems

- 52 RAT
- 53 Landing Gear Hydraulics
- 55 Auxiliary Power Unit
- 56 Engine Driven Generators

Air Conditioning and Environmental Control Systems

- 6 Environmental Control Unit (ECU)
- 21 ECU
- 29 ECU
- 30 Air Conditioning and Environmental Control Systems Control Computer
- 54 Engine Driven Pump

Figure 16.2 Support Systems Layout

emergency power for the flight controls. RATs generate power by converting ram air flow past a turbine into electric current. The components of the auxiliary power system are illustrated in Figure 16.2.

16.5 Hydraulic System

The Guardian utilizes a hydraulic system for landing gear retraction and wheel brakes. One hydraulic unit is dedicated to each strut and one for each wheel. These units operate at approximately 5,000 psi. Figure 16.2 shows the locations of the landing gear hydraulics. Gear bay doors are also operated by these hydraulics.

17.0

WEAPONS INTEGRATION

As reviewed earlier, the primary role of a CAS aircraft is the elimination of hostile ground forces. The primary weapons load of the *Guardian* aircraft is air-to-around weapons, including Air-to-Ground (AGM) missiles, free fall bombs, guided "smart" bombs, and most of all, the 30 mm GAU-8 cannon. It is capable, however, of air-to-air combat, should it need to, and will carry these weapons as well. Total weapons capacity is 19,500 pounds on 12 hard points.

It is understood that a 19,500 pounds weapons load is heavy, especially for an aircraft weighing 50,000 pounds. It must be noted that the short takeoff figures were attained using the design mission load of about 11,000 lbs. If a longer runway is available and high maneuverability isn't necessary, then the heavier load may be carried.

The *Guardian* was designed with a multi-mission role in mind. The aircraft is capable of multiple roles, including basic anti-armor ground support, deep strike, combat rescue escort, maritime strikes, and a ferry mission. (See Figure 17.1)

17.1 The GAU-8

The GAU-8 "Avenger" 30 mm cannon is the centerpiece of the *Guardian* 's weapons system. It is currently carried on the Fairchild A-10, is the largest cannon carried in any aircraft today, and is the only permanently fixed weapons system on the *Guardian*. The GAU-8 has already proven its deadliness in the A-10. It is capable of firing 4200 rounds per

minute, but this is hardly needed, since one round from the 30 mm shells can take out an enemy tank. This awesome firepower does not come without a design price which is the high weight and large size. The gun weighs 3800 lbs loaded, and is a full 21 feet in length. Also associated with a gun this size is the large average recoil of 9000 lbs, which, although mounted with the firing barrel on the centerline of the aircraft, still affects the handling control of the *Guardian*.

17.2 Unguided Freefall Bombs

The primary air-to-ground weapons are the MK-82 500 lb bombs required in the RFP document. The design requirements are to carry 20 of these. The *Guardian* will carry these on the two innermost sets of hard points and will only take up about 60% of the *Guardian*' s weapons capacity, allowing it to be more heavily armed for any scenario. Any bomb type that is rack launched, all the way up to the MK-84 2000 lb bomb, can be carried by the *Guardian*, including cluster bombs. These bombs are targeted and released via the HUD targeting display.

17.3 Guided Freefall Bombs

The previously described bombs are "unguided" weapons. Although the *Guardian*'s targeting system can be used to guide the release of these weapons, once they are released no corrections can be made to guide them to their target. Guided free fall weapons lock on to their targets using electro-optical or laser guiding systems. Small corrections are made by deflecting fins while the ordinance is falling towards its target, providing

pinpoint accuracy. Electro-optical targeting systems are carried on-board the weapon and on board the *Guardian.* One or both are used to lock onto the target and guide it home. Laser guided weapons use an external laser to illuminate the target, then the weapon homes in on this illumination spot. Targeting lasers, such as the LANTIRN system may be mounted on a rotorcraft, may be ground based, or on the *Guardian* itself. Most of these weapons may be carried on all but the two outermost stations. Since guided weapons are more accurate than unguided weapons, they enjoy the advantage of longer range over unguided weapons, keeping the aircraft farther away from hostile fire.

17.4 Air-to-Ground Missiles

The next set of weapons which the *Guardian* may carry is the Air-to-Ground missiles or AGM's. The primary ground attack missile, especially effective against armored tanks, is the AGM-65 Maverick. The *Guardian* is capable of carrying up to 18 Maverick missiles, with room an ECM pod and extra targeting pod if needed. Other types of missiles include Anti-Radar Missiles (ARM's) which focus on the energy emitted by a ground based radar system to guide them in and destroy them. Multiple rocket launchers may be used in anti-armor attacks. The LAU-8 can fire 19 armor piercing rocket rounds within two seconds. These are all targeted using the HUD.

17.5 Air Intercept Missile

Even though the *Guardian* is a CAS aircraft, it is inevitable that it may come up against some air resistance in a battle scenario. For this reason, the *Guardian* is armed with short range heat seeking AIM (Air Intercept Missile)-9 "Sidewinders". These are very effective "fire and forget" type missiles. They are guided to their target by infrared sensors on-board the missiles which home in on the heat signature emitted by the enemy aircraft. The missiles are launched off of dedicated rails at each wing tip. The rails are wing tip mounted to have the best obstacle free launch.

17.6 Special Purpose Weapons

Electronic Counter Measure (ECM) will be carried internally on the *Guardian* . ECM provides an electronic "shroud" around the aircraft by jamming enemy radar, giving the *Guardian* an extra advantage of "invisibility" to the enemy radar, therefore adding an element of surprise.

Defensive equipment pods, such as flares and chaff may be carried if the mission requires bringing the *Guardian* into heavily defended areas. Chaff is used to battle enemy radar by releasing radar reflective material, scattering radar waves, and confusing enemy offensive/defensive systems. Flares are sent out to distract enemy missiles away from the heat signature of the aircraft and harmlessly detonate there.

External fuel tanks can be used alone for ferrying the aircraft long distances or in conjunction with weapons stores for deep strike missions

needing extra fuel. The two innermost hard points are wet and can carry up to 1200 gallons of external fuel.

17.7 Attack Configuration (Low Level Design Mission)

The low level design mission requires an attack configuration of 20 MK 82 500 lb general purpose bombs. these will be carried on the four innermost hard points, with six bombs on the innermost and four bombs on the next innermost on either side of the aircraft. As always, the aircraft will carry the fully loaded GAU-8A and air defence AIM 9L Sidewinder missiles. (See Figure 17.1)

17.8 Deep Strike Mission

The deep strike mission is much like the low level attack, except extra fuel requirements dictate the use of two extra 300 gallon fuel tanks mounted on the two innermost "wet" hard points. The empty tanks may be jettisoned and ditched in a combat situation to improve maneuverability and performance should the *Guardian* encounter unexpected enemy resistance Since battle conditions may be less well known on a longer mission, extra AGM 65 Maverick missiles will be carried for any anti armor requirements.

17.9 Combat Rescue Escort

Many times in a combat scenario, certain troops may be trapped behind or enclosed by enemy forces. In this case, a rescue effort may be called in. This usually involves a rotorcraft capable of vertical landing and take-off. Since rotorcraft are slower and must land in exposed areas, an escort aircraft is extremely desirable. For this mission, four LAU 3 19 round rocket launchers will be carried on stations 4, 5, 8 and 9. These are capable of launching singly or all at once, and are very effective against light armored vehicles. The AGM 65 Mavericks provide necessary accuracy against medium armored vehicles. As always, air defence Sidewinders are carried and the GAU-8A is fully loaded and ready for combat. (See Figure 17.1)

17.10 Maritime Strike

In battle scenarios taking place near bodies of water, many times a close air support is required against a naval force. This would require the aircraft to fly a distance over a body of water. Since emergency landing sights over a body of water are nonexistent, sufficient fuel supply is important, hence the mounting of twin 300 gallon external fuel tanks on the two "wet" points. MK 20 500 lb cluster bombs are very effective in piercing ship hulls and are carried for this reason on stations 5 and 8 on this mission. AGM 65 Maverick missiles are as effective against ships as they are against tanks, and these are carried on stations 4 and 9. Chaff and flares, used in conjunction with the on board ECM are very effective in

confusing ship's defence systems and can be carried as well. (See Figure 17.1)

17.11 Ferry Mission

Ferry missions require the longest range possible, therefore all weapons are unloaded, and the largest possible external fuel tanks are loaded on the aircraft. Two 600 gallon external fuel tanks are fixed to the "wet" points to give the *Guardian* an extra 1200 gallon fuel capacity in addition to its internal capacity. It is also suggested that the GAU-8A cannon system be unloaded to reduce weight and increase range.

18.0

GROUND SUPPORT REQUIREMENTS

The *Guardian* was designed with the idea of having minimal ground support equipment. Since the aircraft will most likely be operating from unprepared surfaces close to the front line of battle, it would be inefficient to require heavy and cumbersome equipment to keep it operating in battle situations. It was also designed to conform as much as possible to existing ground support equipment already in use, so as to minimize cost. In fact, the only specialized piece of ground equipment that is needed is the ammunition loading system for the GAU-8 30mm cannon, and this has already been in use for many years by the Fairchild A-10.

18.1 Fly-By-Wire

The fly-by-wire flight control system was not only designed with good survivability in mind, but also to eliminate the need for a ground based hydraulic pressurizing cart needed by many aircraft to charge the hydraulic system for ground maintenance. The *Guardian*'s control system is based on individual electrohydrostatic actuators at each control surface. Each unit has its own self contained electrically powered hydraulic pump, eliminating the need for an entire system to power up the hydraulic lines to perform ground maintenance.

18.2 Auxiliary Power Unit

The aircraft carries its own self contained Auxiliary Power Unit (APU), allowing it to power up all of its electrical and electronic systems without spooling up the engines or requiring any type of ground based external power supply.

The following is a brief description of the ground based equipment requirements for the *Guardian* :

18.3 Fuel Truck

Fuel requirements are basic for all types of military fighter or attack aircraft. Most require some sort of vehicle to carry the fuel up to where the aircraft is located. The *Guardian* will make use of single point refuelling, with gravity feed refuelling points located on the top of the fuselage just between the two engines. Two separate pressure feed refuelling points are located near the leading edge of each wing. Single point refuelling provides the advantage of fast and simple refuelling by providing a fuel feed system and a vapor return system all in one hose, eliminating extra equipment requirements. (See Figure 16.1 for refuelling points)

18.4 Powered Hoist

A powered hoist, capable of lifting at least 4000 pounds will be required for the loading and unloading of weapons ordnances from the wing undercarriage. Since the *Guardian* is designed to be compatible with all

NATO-pact weapons, all powered hoists currently used for weapons loading are acceptable. Its mid-wing design allows for easier weapons loading than other low or high-wing designs, with the underside of the wing at a comfortable 6.5 feet above the ground, a manageable point for most average human beings to reach and inspect ordinance loading.

18.5 Liquid Oxygen Delivery System

A liquid oxygen delivery system, usually a cart, is required to replenish the oxygen supply to the pilots oxygen system. The fill point is located just behind the cockpit on the right side of the aircraft.

18.6 Ammunition Loading System

The ammunition loading system is the only specialized piece of equipment required for field support of the *Guardian*. This is due to the fact that only one other aircraft in production, the A-10, uses the massive GAU-8 30mm cannon system. The loading system closely resembles the aircraft's own internal hydraulic feed system, loading new ammunition in while simultaneously unloading spent ammunition from the storage drum on the aircraft. The system is very efficient and can have the aircraft loaded and unloaded in less than 13 minutes. The reloading point is located on the left side of the aircraft, right next to the ammunition barrel below and behind the pilots seat.

18.7 Reloading Points

The placements of all the reloading points allows the aircraft to be refuelled, reloaded and replenished simultaneously. Without one operation getting in the way of another, turnaround time and complexity of operations on the ground are reduced.

19.0

COST ANALYSIS

The Guardian life cycle cost was calculated in 1991 dollars using empirical data. This cost includes the entire cost of the aircraft from the moment the design process begins to the time the aircraft is disposed of. The life cycle cost can be broken into four majors areas: (1) Research, Development, Test and Evaluation (RDTE), (2) Acquisition, (3) Operations, and (4) Disposal. This estimate was based on an empty weight of 25,298 lb and a maximum velocity of 520 knots.

The RDTE costs includes the cost of the research aspect of the design and the development work. It also includes the building and testing of two static flight test airplanes and a profit of 7%.

The acquisition cost is the entire expense in manufacturing the aircraft plus a profit of 10%. The production is based on producing 500 as specified in the RFP at an average production rate of 6 aircrafts per month. The result is an aircraft with an acquisition cost of 13.6 million dollars per airplane.

The operations cost includes the expenses for fuel, pilots, maintenance, spares, depot, and other indirect costs. These costs were based on a service life of 20 years and an estimate of 325 flight hours per aircraft. per year with an average mission of 1.3 hours. The operation cost per hour per airplane was calculated at $2390.

The disposal cost is the cost to dispose of the aircraft after it has finished its service life. An approximation of 1% of the total life cycle cost was estimated for this cost.

Table 19.1 shows the numerical breakdown of all of these costs. Figures 19.1, 19.2, and 19.3 shows the percentage breakdown of the life cycle cost, operations cost, and manufacturing cost respectively.

Table 19.1
Life Cycle Cost Breakdown for Guardian
(Note: All costs are in millions of 1991 dollars)

RDTE Cost		
Airframe, Engineering, and Design		122.4
Development, Support, and Testing		39.1
Flight Test Aircrafts (2)		465.9
Engine and Avionics	43.9	
Manufacturing Labor	191.5	
Manufacturing Materials	44.7	
Tooling	160.9	
Quality Control	24.9	
Flight Test Operations		33.5
Test Simulation Facilities		24.8
Finance (10%)		82.6
Profit (7%)		57.8
Total RDTE Cost		826.1
Acquisition Cost		
Airframe, Engineering, and Design		129.0
Program Production		5421.7
Engine and Avionics	2746.2	
Manufacturing Labor	1311.6	
Manufacturing Materials	962.0	
Tooling	231.4	
Quality Control	170.5	
Finance (10%)		616.7
Profit (10%)		616.7
Total Acquisition Cost		6784.1
Operations Cost		
Fuel, Oil, and Lubricants		1832.9
Direct Personnel		2936.7
Indirect Personnel		1849.6
Consumable Materials		264.8
Spares		1438.6
Depot		1335.8
Miscellaneous		616.5
Total Operations Cost		10274.9
Disposal Cost		180.7
Life Cycle Cost		18067
Life Cycle Cost/500 Aircraft		36.1

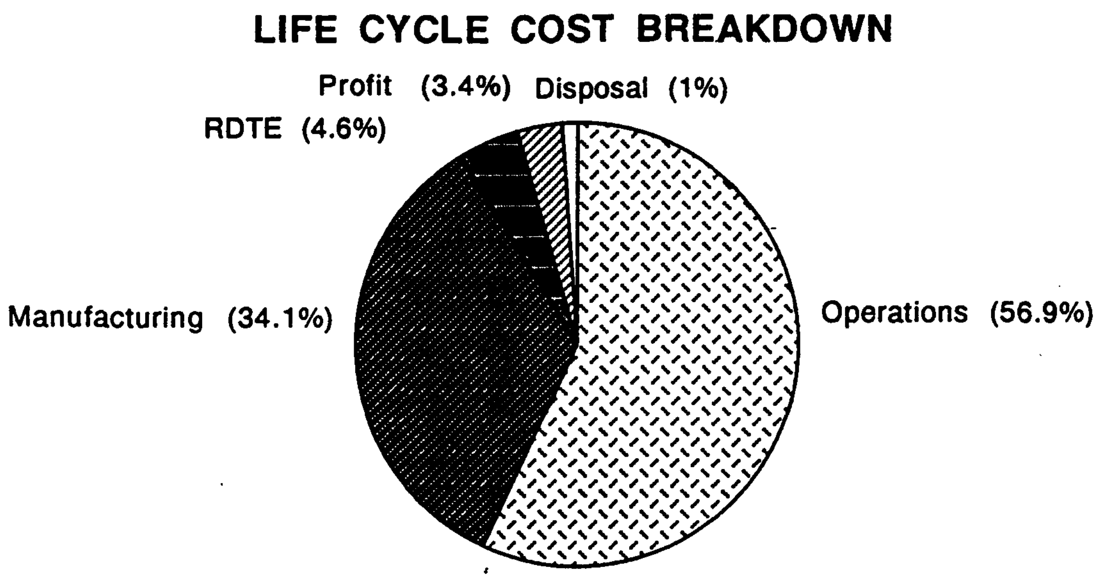


Figure 19.1

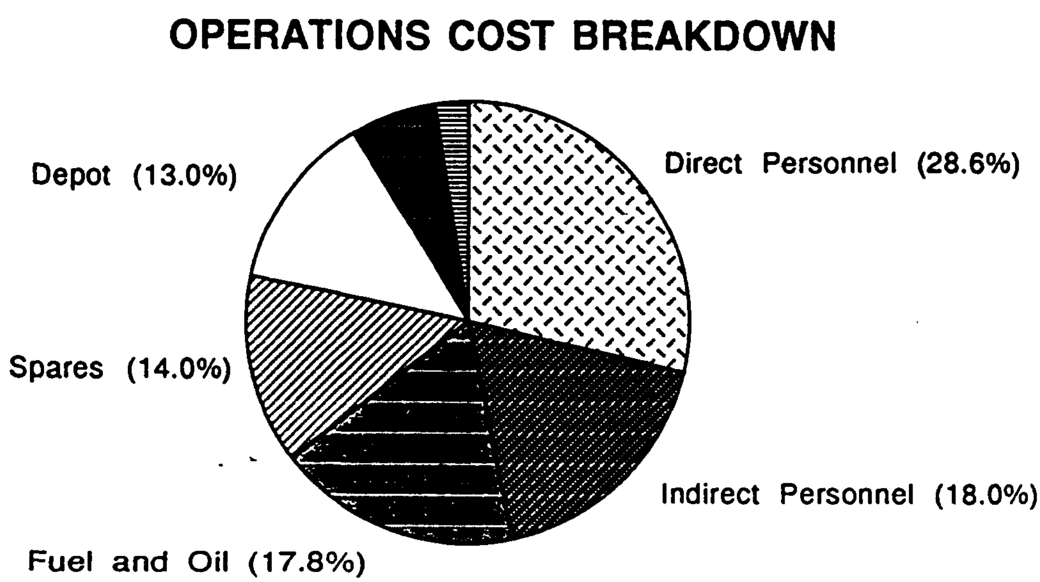


Figure 19.2

MANUFACTURING COST BREAKDOWN

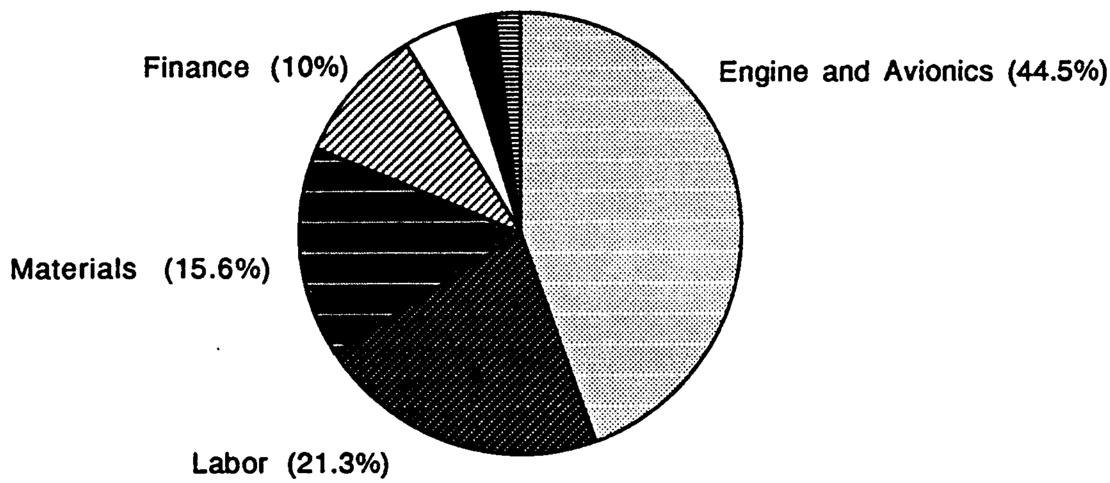


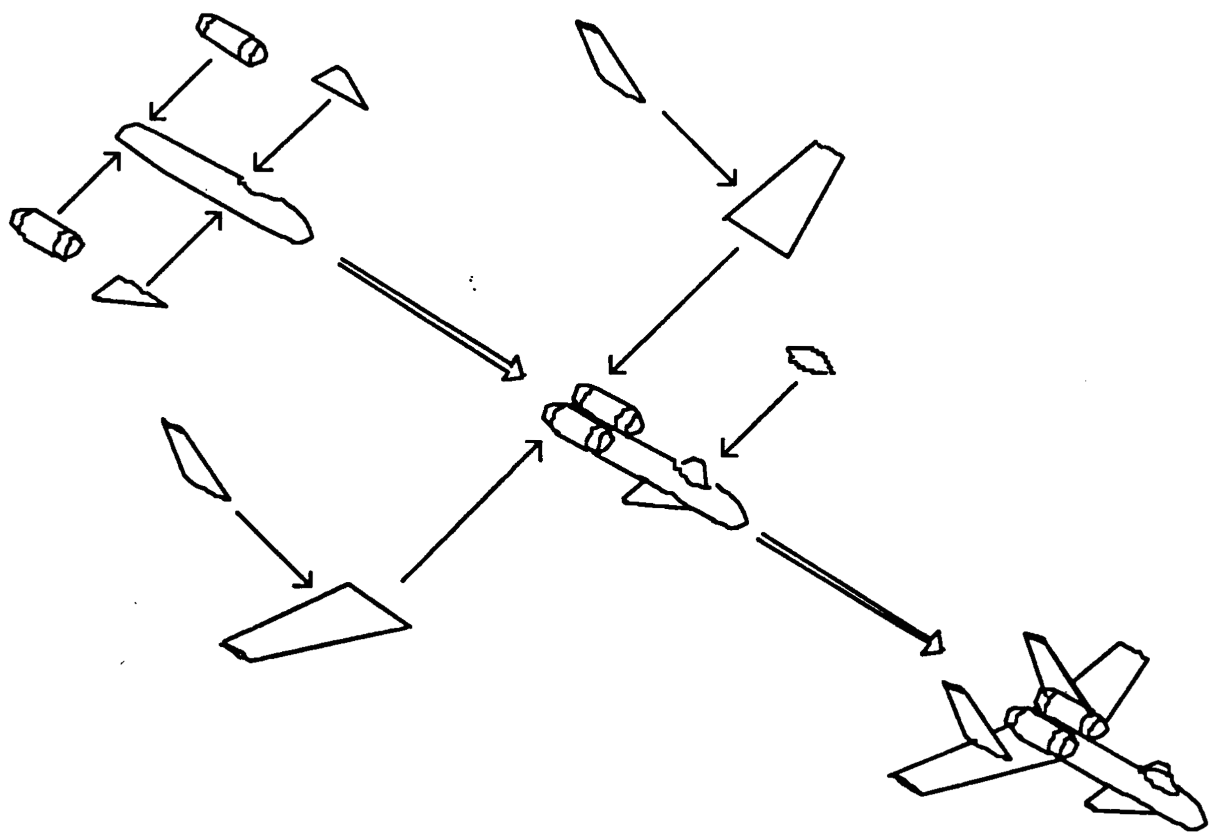
Figure 19.3

20.0

MANUFACTURING BREAKDOWN

The manufacturing breakdown is done in a conventional way. Figure 20.1 shows the order of assembly for the *Guardian*'s individual components. The first components to be assembled to the fuselage are the canards and nacelles, both of which attach to the fuselage directly. The twin engines, being external to the fuselage, makes the installation easier than buried engines, and therefore cheaper. The next section to be added is the wing assembly, which includes the vertical tails already mounted to the wing planform. Finally, the cockpit is covered and all of the main components of the *Guardian* are assembled. Since the engines are not mounted on the wing, it is possible to mount them first. This is advantageous because they would be more difficult to mount if the vertical tails were already in place and causing a hindrance.

Figure 20.1 Order of Assembly of the *Guardian*



21.0

CONCLUSIONS

We have designed the *Guardian* to meet or exceed all of the requirements set out in the supplier RFP, which describes the role of the next-generation close air support aircraft. We feel that the *Guardian*'s configuration is ideal for the CAS role, incorporating high maneuverability and mission flexibility with low IR signature and excellent off-base capabilities. Its ability to takeoff and land on short, unprepared airstrips coupled with its self-sufficiency in ground operations makes it very adaptable to a multitude of geographic locations. With the capability of carrying extensive weapons loads, as well as carrying smaller loads over very long ranges without refueling, the *Guardian* is perfectly suited to the ever-changing CAS environment. The fact that it is a versatile tool, useful in both in ground attack as well as many alternate missions, makes the *Guardian* cost effective, while still achieving the specialized capabilities required by a true CAS aircraft.

Although the canard configuration is as old as is the *Wright Flyer*, today it is still a developing technology. We feel that, in the future, the canard-wing will replace the wing-elevator as the "conventional" configuration.

By no means is the design of the *Guardian* complete. This report is a "preliminary" design. Other areas have to be studied and restudied before the *Guardian* is complete. A list of problem areas we encountered, which require further study, is given below.

-Canard-Inlet interference: Angle-of-attack at which the canard wake affects the engine inlet and compressor efficiencies due to downstream turbulence.

-Canard/Wing Coupling Effects: Finding the best compromise between maximizing lift performance and required canard incidence angle for longitudinal trim .

-C.G Travel: Reducing C.G. travel during flight.

-Handling Characteristics: Incorporating flight control systems that maximize performance, while minimizing pilot workload.

Although we have limited these problems in our final design proposal, the addition of new information on these subjects will minimize possible problems further along in the design process.

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